A B S T R A C T

VISUAL INSPECTION, ITS AUTOMATION AND APPLICATION IN THE TEXTILE INDUSTRY

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The application of visual inspection techniques to textile manufacturing is an area of major significance. The majority of fabric and garment inspection in the Industry today is carried out by human examiners. These inspection processes are time-consuming, labour intensive and subject to human judgment and error. With the increasing efficiency of other production processes, inspection is contributing an increasing proportion to the total production costs. Thus, any automation of the inspection process offers considerable potential advantages in reduced costs, increased throughput speeds and more consistent fault detection and identification.

The aim of this research is to investigate the application of automated visual inspection to the knitted fabric examination process. To this aim, an industrial study of single jersey and 1x1 rib cotton fabric defects has been carried out with the collaboration of 5 knitwear manufacturers. From this information a defect classification has been formed based on the visual features of the defects. An expert system approach has been developed to input the textile expert knowledge into a computer. Using this software, a configuration is proposed for a commercial automatic fabric inspection system.

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C O N T E N T S

		Page No.
1.0	Chapter 1 - The Knitwear Industry	1-0
1.1	Introduction	1-1
1.2	Effect of Competition on Knitwear Manufacturing	1-3
1.2.1	Analysis of Costs in Jerseywear Garment Manufacture	1-5
1.3	Impact of Technological Developments on Knitwear Manufacturing	1-10
1.3.1	Knitting Process	1-12
1.3.2	Dyeing and Finishing Process	1-13
1.3.3	Make-up Process	1-13
1.4	Identification of the Problem	1-15
1.5	The Way Forward	1-18
1.6	Summary	1-19
1.7	Structure of the Thesis	1-20
2.0	Chapter 2 - Fabric Inspection in the Knitwear Industry	2-0
2.1	Introduction	2-1
2.1.1	Reasons for Inspection in the Knitwear Industry	2-2
2.2	General Inspection Methods	2-4
2.3	Fabric Inspection in the Knitwear Industry	2-6
2.3.1	Inspection during Knitting	2-6
2.3.1.1	Specialised Yarn Feed and Storage Systems	2-8
2.3.1.2	Needle Sensor Devices	2-8
2.3.2	Inspection after Knitting	2-9
2.3.2.1	Development of Fabric Inspection Techniques	2-11

Page No.

2.3.2.1.1	Manual Techniques	2-11
2.3.2.1.2	Mechanical Techniques	2-14
2.3.2.1.3	Semi-automated Techniques	2-22
2.4	The Role of the Human Inspector	2-23
2.4.1	Factors affecting Inspection performance	2-26
2.4.1.1	Inspector variables	2-29
2.4.1.1.1	Eyesight	2-30
2.5	Summary	2-31
3.0	Chapter 3 - Visual Inspection Techniques and Applications	3-0
3.1	Introduction	3-1
3.2	Image Processing Techniques	3-2
3.3	Continuous Illumination Techniques	3-4
3.4	Laser Scanning Techniques	3-5
3.5	Expert Systems	3-6
3.5.1	Industrial Applications of Expert Systems	3-8
3.5.2	Knowledge-based Computer Vision Techniques	3-9
3.6	Summary	3-10
4.0	Chapter 4 - System Specification and Strategy	4-0
4.1	Introduction	4-1
4.2	Industrial Requirements	4-3
4.2.1	Defect Detection	4-4
4.2.2	Defect Identification	4-5
4.2.3	Information Feedback	4-5
4.2.4	System Flexibility	4-6
4.2.5	Efficiency Monitoring	4-7

Page No.

4.3	The Way Forward	4-7
4.4	Summary	4-8
5.0	Chapter 5 - Defect Classifications	5-0
5.1	Introduction	5-1
5.2	Review of Defect Classification Schemes	5-1
5.3	Survey of Defects - Single Jersey and 1x1 Rib, Cotton Garments	5-5
5.3.1	Method of Approach	5-6
5.3.2	Results of Survey	5-8
5.3.3	Discussion of Results	5-13
5.4	Development of a Defect Classification Scheme	5-16
5.4.1	Feature Tree Approach	5-17
5.4.1.1	Description of Defects and Defect Types	5-19
5.4.1.2	Industrial Survey of Defect Terminology	5-24
5.4.1.3	Feature Tree Defect Classification	5-32
5.4.2	Numerical Description Approach	5-44
5.4.2.1	Numerical Description Classification	5-45
5.4.3	Technical Structure Analysis Approach	5-47
5.4.3.1	Technical Structure Analysis Classification	5-50
5.5	Summary	5-51
6.0	Chapter 6 - Interactive Capabilities of an Automated Fabric Inspection System	6-0
6.1	Introduction	6-1
6.2	Defect Causes and Remedial Actions at Source	6-3
6.3	Summary	6-3

		Page No.
7.0	Chapter 7 - Development of Intelligent Knowledge-Base System for Defect Recognition and Classification	7-0
7.1	Introduction	7-1
7.2	Prototype Image Processing Computer System	7-2
7.3	Development of an Automated Fabric Inspection System	7-4
7.4	Development of Defects Database	7-4
7.4.1	Feature Tree Approach	7-5
7.4.2	Feature List Approach	7-11
7.4.3	Knowledge-base Driven Image Classification Approach	7-15
7.5	IKB System Implementation	7-17
7.6	Summary	7-18
8.0	Chapter 8 - Overview and Further Research	8-0
8.1	Introduction	8-1
8.2	Overview of the Work	8-2
8.3	Refinements	8-4
8.4	Further Research	8-6
8.5	Summary	8-7
	References	i-ix

LIST OF TABLES

No.		Page No.
1	Single Jersey Fabric Cost	1-5
2	Double Jersey Fabric Cost	1-6
3	Single Jersey Inspection Costs	1-8
4	Double Jersey Inspection Costs	1-9
5	Factors which could affect Inspection Performance	2-28
6	Company Details	5-7
7	Breakdown of Total Number of Garments Examined	5-8
8	Breakdown of 1x1 Rib Garment Defects	5-9
9	Significance of Defect Occurrence at Defined Manufacturing Stages - 1x1 Rib	5-10
10	Breakdown of Single Jersey Garment Defects	5-11
11	Significance of Defect Occurrence at Defined Manufacturing Stages - SJ	5-12
12	Extracts of Information from Tables 7 and 11	5-13
13	Summary of Results	5-18
14	Significance of Terms used to Describe Vertical Defects	5-26
15	Significance of Terms used to Describe Horizontal Defects	5-27
16	Significance of Terms used to Describe Regional Defects	5-28
17	Significance of Terms used to Describe Dispersed Defects	5-29
18	Synonym Lists from Survey Results	5-31
19	List of Numerical Parameters	5-32
20	Causes of Defects	6-4
21	Recommendations for Remedial Actions at Source	6-5

LIST OF FIGURES

No.		Page No.
1	The Cost of Quality Control	1-7
2	Framework of Jerseywear Manufacturing Route	1-11
3	Presentation Area of a Garment	2-10
4	Development of Fabric Inspection Techniques	2-11
5	Manual Inspection Table	2-12
6	Fabric Inspection Machine with Roller Arrangement	2-16
7	Fabric Inspection Machine with Mirror Arrangement	2-18
8	Open-Width Fabric Inspection Machine	2-21
9	Graph of Percentage S.J. Rejects Attributable to Knitting Defects Against Percentage Fabric Examined	5-15
10	Illustration of Walewise/Coursewise Directions	5-20
11	Frequency of Occurrence of Defect Types 1x1 Rib Fabric	5-33
12	Frequency of Occurrence of Defect Types Single Jersey	5-34
13	Fabric Construction in Grid Format	5-48
14	Prototype Image Processing Computer System	7-3
15	Integral Parts Intelligent Knowledge-Base System	7-4
16	Key to Figures 16a-16d	7-6
16a	Feature Tree Structure - Regional Defects	7-7
16b	Feature Tree Structure - Vertical Defects	7-8
16c	Feature Tree Structure - Horizontal Defects	7-9
16d	Feature Tree Structure - Dispersed Defects	7-10
17	Database for Feature List Approach	7-12
18	An Intelligent Knowledge-Base System	7-16

LIST OF APPENDICES

No.		Page No.
A	Details of Inspection Methods Employed by Companies Involved in Industrial Survey	A1
B	Photographs of Examples of Defects	B1-B10
C	Feature Tree Defect Classification Program	C1-C6
D	Feature List Defect Classification Program	D1-D3
E	Defect Causes Program	E1-E4
F	Knowledge-Base Driven Image Classification Approach - Program to Generate Database	F1-F6

CHAPTER 1

THE KNITWEAR INDUSTRY

The bitterness of poor quality
is left long after the sweetness
of low price is gone.

P.G. Noble

1.0 The past two decades have been ones of significant change for fabric manufacture in the knitwear Industry. Chapter 1 reviews the current status of the Knitwear Industry, discusses the effects of developments in manufacturing processes which, together, form the production route.

1.1 INTRODUCTION

In industrial history, textiles qualify as one of the oldest industries, with weaving perhaps appearing first with the old stone age cultures circa 10,000 BC (Ponting, 1981). It is noteworthy that the term 'textiles' was used only to define woven fabrics (The Textile Institute, 1975), but since the advent of a diverse range of manufacturing methods, the term now encompasses all activities in the trade.

The structure of modern industrial textiles is marked clearly by its division into sectors. To form a general overview of the Textile Industry is complicated because the scene in any one sector is not necessarily a microcosm of the whole. The influences and requirements of the market, technological developments and economic considerations of a particular sector make its industry quite unique.

A sector of particular current interest, and now regarded as the main alternative method to weaving in the production of fabric, is the Knitwear Industry. In recent years, knitting has captured a large part of the long-established field of the traditional woven fabrics. The enormous potential of knitting with its unique capacity for producing shaped, form-fitting articles with great elasticity in a huge diversity of colour, pattern and texture is unmatched by any other fabric-forming technique. Knitwear manufacturers, seeking to exploit these characteristics to the full, have welcomed the changes and developments that have occurred, the outcome of which has served to enhance characteristic versatility, flexibility and adaptability in both garments and production methods.

Within the Knitwear Industry there are distinct sectors. These sectors are distinguishable by the manufacturing techniques employed and the end use item produced. The cyclic nature of the Knitwear Industry (Nightingale, 1986), has created particular problems over the years. Whilst some sectors of the Industry such as hosiery and weft knit underwear have remained relatively stable, others, including jerseywear, have experienced enormous growth followed by major decline. During the last period of growth in the sixties (ibid.), the knowledge of expanding markets and increasing demand for jersey fabric and machinery are undoubtedly factors which influenced the introduction of technological developments into computer aided patterning systems (Burnip, 1974). Since this introduction of electronics to the Industry, manufacturing technology has undergone significant changes and continued to do so throughout the late seventies which saw the commencement of a period of recession. As a result of this decline, jerseywear manufacturers have become increasingly aware of the key ingredients of inefficient manufacturing which has led to a combination of poor productivity and excessive wastage during production. Thus manufacturers are studying production operations closely, with a view to reducing costs wherever possible. Several causative factors have encouraged the current cost-conscious climate of which the following two are deemed to be contributors.

1.2 EFFECT OF COMPETITION ON MANUFACTURING

One of the Industries underlying difficulties is the relative ease of entry of imported knitwear garments from Less Developed Countries and of imported knitted fabrics from Developed Countries (Colley, 1985). Both have led to damagingly intensive price competition. Competition between manufacturers has resulted in an ever-widening choice for consumers to pick from; with fabric and garment quality becoming a major criterion for selection (United Nations, 1972). To compete successfully, the manufacturers must obtain for the customer the quality level that they have come to expect, at a minimum manufacturing cost. In production, this cost is generally higher than first estimated due to factors such as:

1. the production of defective fabric not fit for normal sale to acceptable levels.

2. processing difficulties.
3. inferior garments (rejects or seconds).
4. poorly-defined quality standards.
5. product returns by the customer, with subsequent risk of customer loss.

According to Noble (1972), the actual cost of faults reflects itself in two additional ways:

6. operative irritation and management frustration arising from the disturbance of planned production by the interference factor of faults causing delays in the operation cycle.
7. increased overheads due to additional inspection and planning costs.

With the emphasis on faults, the costs involved in fabric and garment manufacture have received particular attention (Shirley Institute, 1970; Wira, 1971; Levy, 1973). Investigations were conducted in factory environments to determine the actual costs of different types of faults in woven fabrics and shirtings. From these studies, Knoll and Wolfe (1975), surmised that the adequacy of the methods employed for fabric inspection and grading have a direct relationship to the final cost of faults to the garment manufacturer. The value of fabric has a significant impact on the final cost of the garment since fabric cost represents approximately one-third to one-half the total cost of the manufactured product (Kolbeck, 1984). Within the woven and warp knitted sectors of the Industry, valuable information has been collected on the nature of costs in fabric and garment manufacture. From the few tests carried out with knitted fabrics, Levy (1973), suggested that faults in knitted fabrics were generally more expensive than those in woven cloths. One reason is the larger size of many faults in knitted fabrics.

1.2.1 ANALYSIS OF COSTS IN JERSEYWEAR GARMENT MANUFACTURE

Based on information made available, in 1984, by a leading British knitwear manufacturer, an analysis of the costs involved in the production of single jersey and double jersey 1 x 1 rib, cotton garments has been carried out. Tables 1 and 2 summarise the single and double jersey fabric costs as a percentage of total manufacturing costs (raw materials, labour and overheads).

TABLE 1

SINGLE JERSEY FABRIC COST

TYPE OF GARMENT	FABRIC COST (%age. total man. cost)
Ladies brief + motif	16.4
Ladies brief + motif	17.3
Ladies mini brief	42.7
Ladies short sleeve top	29.8
Mens brief	23.4

TABLE 2

DOUBLE JERSEY FABRIC COST

TYPE OF GARMENT	FABRIC COST (%age. total man. cost)
Babies polo neck top	32.4
Boys vest	37.1
Boys 'v' neck vest	40.1
Boys short sleeve top	38.5
Ladies short sleeve top	36.1
Ladies top	31.9
Mens short sleeve vest	53.1

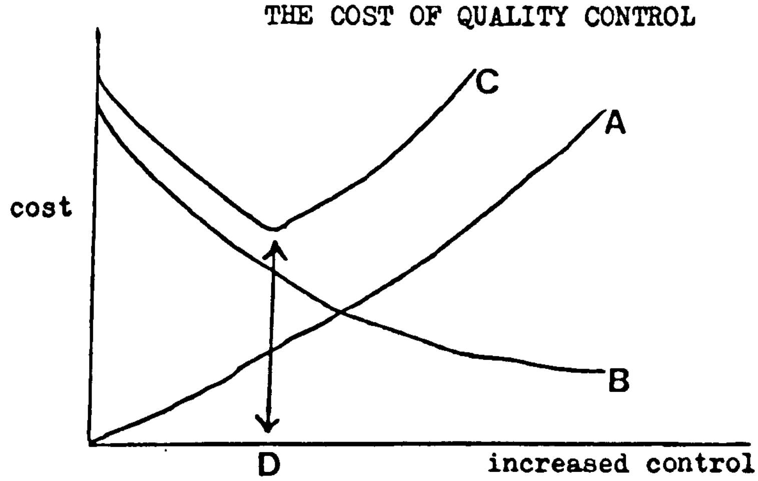
The information in tables 1 and 2 highlights the following points:

1. fabric costs represent a significant proportion of total manufacturing costs.
2. the value of fabric is most meaningful to the manufacturer when considered in the context of the garment produced.

To extrapolate these points, the emphasis of excessive fabric costs for the manufacturer may be attributed to fabric faults. In addition to producing garment rejects, faulty fabric can adversely affect fabric utilisation and, as fabric can represent over 50% of the total manufacturing cost of a garment, faults caused during knitting can be extremely serious. An important aspect in the cost of faults is the various methods of fault inspection employed by the Knitwear Industry. Fabric inspection is a management tool to retain costs (Borestrom, 1985), by way of reduced customer complaints and increased quality of the end product. Inspection is one of the manufacturing processes employed as part of the quality control programme which is implemented in order to eliminate, as far as possible, factors that lead to increased production costs and lower quality merchandise. Costing is one of the most important factors in quality control since the extent to which control is exercised depends on the relative cost of the control scheme compared with the cost of poor quality owing to waste, processing difficulties, rejects, seconds and returns etc. A report by UNIDO 1972, indicates a general cost/quality control relationship (figure 1).

FIGURE 1

THE COST OF QUALITY CONTROL



As control effort is increased, there is a corresponding increase in expenditure on the control scheme (curve A) and, simultaneously, a corresponding decrease in the cost of poor quality (curve B). The actual cost to the firm (curve C) is the sum of the costs of the control scheme and of poor quality. As the amount of control is increased, the actual cost decreases to a minimum and then increases again for a greater quality control effort. The optimum control (D) represents a compromise since perfect quality is an ideal of no economical worth.

The overall inspection costs in relation to production costs (labour and overheads) in jersey manufacture are shown in Tables 3 and 4.

TABLE 3

SINGLE JERSEY INSPECTION COSTS

TYPE OF GARMENT	INSPECTION COST (%age. of production cost)
Ladies brief + motif	7.5
Ladies brief + motif	7.3
Ladies mini brief	9.2
Ladies short sleeve top	13.5
Mens brief	10.8

Inspection cost includes:

50% fabric examination after knitting

20% fabric examination after dyeing

200% garment examination during and after make-up

TABLE 4

DOUBLE JERSEY INSPECTION COSTS

TYPE OF GARMENT	INSPECTION COST (%age. of production cost)
Babies polo neck top	6.8
Boys vest	6.02
Boys 'v' neck vest	6.9
Boys short sleeve vest	7.2
Ladies short sleeve top	19.1
Ladies top	22.3
Mens short sleeve vest	9.4

Inspection cost includes:

10% fabric examination after knitting

20% fabric examination after dyeing

200% garment examination during and after make-up

The information in Tables 3 and 4 highlights the following points:

1. the inspection process exercises a considerable influence on the production costs of the garment.
2. in many cases, the higher the value of the garment the greater the cost of inspection.

Because of increased competition, inspection has become an essential part of the drive to keep quality high while keeping prices down. The value of fabric in jerseywear garments, coupled with the cost of inspection, contributes significantly to the overall manufacturing cost of the garment. The occurrence of faults during production of fabric, combined with inadequate inspection, inevitably increases the cost of garment production to unacceptable excesses.

1.3 IMPACT OF TECHNOLOGICAL DEVELOPMENTS ON KNITWEAR MANUFACTURING

Changes are continually taking place in the world socially, economically and technically. These changes affect the environment within which organisations must operate. Organisations, intent not only on survival but on success, respond to the rapidly changing needs of the environment by upgrading traditional systems and methods.

Since the sixties, rapid developments in scientific, social and economic areas have stimulated and contributed to significant changes in computer hardware and software (Sanders, 1973). In the last seven years, several separate factors - one being technological advancements - have been operating together to force the pace of change in manufacturing industry (Alston and March, 1984). One such field where major changes have occurred is in the Knitwear Industry. In previous years, the Knitwear Industry has tended to lag behind most others with respect to technical research and development and so, consequently, with machinery. In an effort to recapture a dominant place in the world market, new machinery using microelectronics are being implemented at a rapid pace. Today, electronic controls and computer-aided systems have become state of the art technology. These advances have accelerated the industry forward at a tremendous rate, so much so, that manufacturers are looking towards increased line speeds and greater productivity and efficiency. Figure 2 outlines the framework of operations in the production of jerseywear garments. In the ensuing sections, the major developments influencing these processes will be reviewed.

FIGURE 2

FRAMEWORK OF JERSEYWEAR MANUFACTURING ROUTE

KNITTING

FABRIC EXAMINATION

DYEING

SHADE CHECK

FINISHING

FABRIC EXAMINATION

MAKE-UP+
inspection

FINAL PRESS

GARMENT INSPECTION

PACKAGING/WAREHOUSE

1.3.1 KNITTING PROCESS

Developments in the knitting field have largely been concentrated in the advancement of electronic facilities. Electronic striping and electronic selection are amongst those for circular machinery allowing quicker and simpler pattern changes, faster production rates with fewer distortions in knitting (Gross, 1984). Aside from electronics, or perhaps because of the impetus provided by the use of computers on the machinery building level, there has been a host of new machinery developments over the last couple of years. According to Knapton 1974, knitting, more than most other industrial technologies, lends itself to new innovation by the very nature of the product and the fashion consciousness of the textile market.

New developments include the use of compound needles for the first time on circular jersey equipment. The use of such a needle offers the attainment of higher speed factors and greater productivity (Gross, 1984). With all these developments, the face of the knitting operation is changing. For example, in the 1950s and 1960s, the trend among knitters was towards volume production where a particular style was churned out month after month or even year after year. The trend today is towards shorter runs and perhaps more complicated designs. Shorter runs and the impact of imports has led manufacturers to be more flexible in their production. The change in attitude has almost certainly been assisted by the advent of the application of computer and electronic controls to knitting equipment.

1.3.2 DYEING AND FINISHING PROCESS

Computer control in dyeing and finishing processes is advancing in the areas of machine control and dyehouse management. The dyeing and finishing sector of the Industry is extremely interested in advanced instrumentation since it is hard-pressed to meet the demands for productivity and to maintain efficiency in keeping redyes at a low minimum. Computer involvement has been in evidence for a number of years. For some dyeing and finishing plants (Suchecki, 1970), every step of the dye cycle, except for loading and unloading, is under automatic control.

With the ever-increasing quality standards and increased fabric production speeds, particular care has to be taken to finish fabric without weft distortions. To meet demands, developments in finishing process control instrumentation continue to emphasise improved versatility, efficiency and productivity (Klopsch, 1982; Holme, 1984).

1.3.3 MAKE-UP PROCESS

The long term goal of total automation throughout the cutting and making-up operations is coming increasingly to the fore. The development of flexible manufacturing systems comprises two major components - the automated handling of flexible materials and the automated cutting and joining of flexible materials. One of the fundamental problems in traditional making-up operations is that fabric is floppy and requires extensive handling. A Shirley Institute study (Walter, 1985) quantified the time spent on fabric handling. In comparison with actual sewing, it shows 50% handling to 20% sewing. To speed up handling, robots and other automatic handling devices are gradually being introduced into manufacturing processes (Taylor et al, 1983; Marsh, 1984; Teague, 1984; Taylor, 1985). Robotic techniques are being researched and applied as part of a high technology response to a need for production methods that economically produce consistent high quality garments. Automatic cutting techniques are well advanced and operating in some larger garment factories already (Donner, 1981). As a widespread application in industry, automatic sewing was once confined to decorative stitching and motifs. Machines are now available which sew genuine seams automatically (Colley, 1985). Technological developments have taken place within the various stages of the make-up process. Research at Durham (Sterling et al, 1983) is geared towards an integral automated garment assembly system, capable of picking up a garment piece from a stack of pre-cut material and presenting it and feeding it through a sewing machine. The introduction of robotics to an integral automated garment assembly system has stimulated interest in novel techniques for joining fabrics. A process traditionally carried out by sewing is being considered for replacement by glueing or merging through ultrasonics or lasers (O'Neal, 1984).

The technological advancements within the knitting, dyeing and finishing and making-up processes are occurring in response to a need by industry for higher productivity with consistent high quality, minimal costs and greater flexibility in manufacturing. These developments play a critical role in sustaining the industry in the world market.

Whilst many manufacturing processes are undergoing rapid change, certain basic processes have not changed in generations. Much of the equipment in use, designed for manual operations, has not changed significantly for 100 years or more. One such process which has lagged behind in terms of technological advancements is the inspection process.

1.4 IDENTIFICATION OF THE PROBLEM

Industrial inspection is the examination and testing of products, components and materials under factory conditions, usually with two aims in view: to detect and reject all that can be classed as defective and to assist in the control of quality of output (Applied Ergonomics, 1970).

As industrial processes in the manufacture of a jerseywear garment have become more automatic, the role of inspection has gained in importance. Whether to pass or to reject a product has become one of the major decisions in production and consequences of poor inspection may be far-reaching. On the one hand, lack of vigilance or bad judgment in inspection may cause dissatisfaction among customers, showing itself in the return of faulty goods and the loss of customer; on the other, poor inspection is liable to raise the cost of production by unnecessary stoppages of machines or interruption in the flow of production, or by the production of large amounts of waste material through failure to take action at the right moment. The faster the machines and processes in industry, the more critical become the decisions and actions of the inspector.

Technological advances in recent years have accelerated the industry forward at a tremendous rate. The knitwear manufacturing industry is looking towards increased line speeds and greater productivity and efficiency. Manufacturers are finding it a costly task because traditional manufacturing processes such as quality control and, more specifically, inspection are severely overburdened in attempting to meet these criteria. The net result is the undesirable and costly production of reject fabric and garments - some inevitably reaching the customer - and creating processing difficulties along the manufacturing route.

As shown in figure 2, fabrics and garments are inspected at several stages in the production process. All garment inspection and most fabric inspection is carried out by trained human examiners. By the very nature of the work, such processes are comparatively slow and expensive. With the increasing efficiency of other production processes, inspection is contributing an increasing proportion to the total production costs.

Defect recognition in materials forms an essential part of the inspection process in the knitwear manufacturing industry. The sub-process of fabric inspection after knitting has a significant role to play in the overall fabric production process. Because products accumulate cost, the earlier in the production process inspection is carried out, greater is the possibility of saving money.

An industrial survey of reject jerseywear garments carried out in 1984, revealed that approximately 40% of total reject garments may be attributed to knitting defects (results of survey discussed in chapter 5). Whilst some defects are apparent in raw materials, many faults do not manifest themselves until the raw material is converted into fabric form via the knitting process. Of the companies that have collaborated with the research, a practical study of the production processes has shown that, in all cases, these firms have come to adapt themselves to the results of poor inspection. Due to the absence of alternative improved inspection techniques, efforts are centred on rectification or down-grading at final inspection. In recent years, several kinds of attempts to automate the fabric inspection process have been reported mainly by textile and electronics engineers. However, these studies have not yielded sufficient results to develop an automated fabric inspection system for practical use. These developments are reviewed in chapter 3.

1.5 THE WAY FORWARD

Visual inspection is an area open to extensive exploitation since the costs involved in traditional manual inspection are high and thus capital investment on visual inspection may be quickly recovered. The efficient detection and identification of faults in knitted structures, either on the knitting machine or during post-knitting operations, is a major consideration in knitted fabric and garment production. It is the growing significance of the inspection process itself which has stimulated an interest in the mechanics of the operation. The need to design and to automate industrial operations and procedures based on the known capacity of the human operator is being increasingly recognised (West, 1982; Naughton, 1985).

The decreasing cost and increasing power of small computers, concurrent with developments in image processing techniques, make possible sophisticated image processing at a reasonable cost. Any automation of the fabric inspection process offers considerable potential advantages in reduced costs, increased throughput speeds and more consistent fault detection and identification.

The way forward proposed in the present research is towards the automation of the inspection process by means of an integral computer vision and defect knowledge base system.

1.6 SUMMARY

A common theme stimulating technological developments in the Knitwear Industry incorporates greater productivity, more consistent quality and reduced costs. Existing inspection processes are proving to be unsatisfactory in meeting the increasingly high standard of output from other processes. For inspection to be successful in controlling the quality of output in the primary stages of production, a high standard of efficiency is required. The high percentage of reject jerseywear garments caused by knitting defects is widespread evidence that standards of inspection in industry tend to be very low.

In the context of the total production process, chapter 1 identifies the fabric inspection process as one operation where significant improvements are needed by the Industry. Computer developments have advanced to a level where the automation of the inspection process is becoming a viable proposition. Taking into consideration the requirements of Industry, development of an automated system for fabric inspection is proposed as the way to fulfill the needs of knitwear manufacturers at this time.

1.7 STRUCTURE OF THE THESIS

The path of developments in the Knitwear Industry is a fascinating one. Chapter 1 adopts an historical approach in providing the reader with a broad overview of the Industry and the processes involved in jerseywear garment manufacture. Changes to the manufacturing environment have influenced the technological developments that have occurred. The impact, both positive and negative, of new automation technology on manufacturing processes is discussed, revealing the adverse effects of these developments on the inspection process. In acknowledgement of developments that have taken place in computer vision techniques, automation of fabric inspection is the central theme of the thesis.

Chapter 2 sets out to review in greater detail developments that have taken place in fabric inspection methods which are used in the Industry today. Taking into account the growing significance of the human inspector in current inspection operations, the factors affecting inspection performance have been determined. Human vision is crucial to the inspection task. Two major variables in human vision are discussed, these being visual acuity and eye fixations.

The application of visual techniques to industrial inspection processes is a rapidly growing technology. Chapter 3 reviews the different techniques and their respective applications to industrial problems. Emphasis is placed on those applications concerning the visual assessment of textiles as this represents a significant introduction of new technology to the field. The development of an automated fabric inspection system with industrial applicability must take into consideration the requirements of industry in terms of quality, costs and the environment into which the system is to be integrated. Chapter 4 investigates some of these requirements and outlines the strategy for development of a system. In response, an intelligent knowledge-based system is proposed as a viable approach to automation of fabric inspection.

As a result of the findings in Chapter 4, a literature survey of defect classification schemes is reviewed in Chapter 5. With no existing classification to adequately supply the standardised defect information required, an industrial survey of defects has been conducted. To present the results of this survey, three approaches to the development of a defect classification scheme are described.

In Chapter 6, the interactive requirements of an automated fabric inspection system are discussed. In the current industrial environment, information feedback/feedforward plays a major role in efficient inspection. A study of defect causes and possible remedial actions at source has been conducted with the intention of building this knowledge into an Intelligent Knowledge-Base System (IKBS) for automatic feedback.

Two aspects of developing an IKB System are knowledge acquisition (chapters 5 and 6) and integration of the knowledge into a computer system. Chapter 7 describes the three component parts of a system and concentrates on the development of the defects database component, for which three approaches are described. Implementation of the system in an industrial environment highlights the need for real-time processing. To achieve processing of sufficient performance, the use of a parallel processing system is introduced.

To conclude, an overview of the research is provided in chapter 8 and areas of refinement discussed. Taking a wider viewpoint of the application of the work conducted to date, further research is proposed into the study of automating the garment inspection process of which fabric inspection is a significant aspect.

CHAPTER 2

FABRIC INSPECTION IN THE KNITWEAR INDUSTRY

Man is the measure of all things.

Protagoras

2.0 A detailed study of current fabric inspection methods in the Knitwear Industry has been conducted. Chapter 2 highlights developments in these methods and investigates the effectiveness of the role of the human inspector.

2.1 INTRODUCTION

As the garment proceeds through a complicated array of processes before the final product appears, a system of product and sub-product inspection is required to identify processing faults. A full inspection at each manufacturing stage may be carried out, but it is usual to examine only a sample and to concentrate on styles and types that are known to be prone to faults. The amount of inspection depends, largely, on the type of garment, the quality and the price range. Inspection, to be effective must be immediate. Goods should be inspected as close to the time of manufacture as possible. The advantages of immediate inspection are as follows:

1. defects may be corrected or removed as close to the source as possible, minimising the quantity of fabric and/or garments produced.
2. immediate inspection allows early feedback to production areas concerning the level of quality in manufacturing.
3. considerable financial savings are possible in minimising time and effort expended on reject goods.

2.1.1 REASONS FOR INSPECTION IN THE KNITWEAR INDUSTRY

The consequence of considerable emphasis on quality of the product is that, throughout the Knitwear Industry there tends to be 100% inspection of all items leaving factories. However, even if there were not such a strong retail requirement, manufacturers would probably still require 100% inspection because of the nature of production in the Industry. The initial production stages from yarn to knitted fabric are highly mechanised and capital intensive. From there on, the process is relatively labour intensive in making-up and finishing of the garments, allowing considerable scope for error. This is further aggravated since fasion trends dictate that manufacturers change their styles at frequent intervals, resulting in production runs of approximately six weeks in duration in some instances. Other reasons for inspection fall into four general categories.

COSTS

Inspection takes place in order to minimise those defects which cause excess cost to the manufacturer and to reduce fabric wastage resulting from faulty fabric. There are distinct advantages to effective inspection procedures directly after knitting as, the further the faulty fabric progresses along the manufacturing route, the more costly the fault becomes. Additional costs are incurred in time and effort expended in dealing with reject items.

QUALITY

Effective inspection procedures allow the quality level of the product to be monitored at each stage of manufacture and also to provide some measure of performance in these areas. In the case of fabric inspection, location of the inspection operation on the knitting plant creates an awareness of monitoring of the quality level of the knitted fabric and contributes towards production of optimum fabric quality from the knitters.

CUSTOMER RELATIONS

Two major aims of inspection are to detect and reject all that can be classed as defective before the final product leaves the factory and to ensure a consistent level of acceptable quality merchandise. Inspection plays an important part in attracting new customers and enhancing relationships with existing customers, thus contributing towards:

1. minimising faulty garments which reach the customer.
2. producing goods to meet the particular quality level.
3. delivering goods on time.
4. offering competitive prices for merchandise.

Manufacturers seek to generate as little cheap, competitive merchandise, to the 'factory shop' outlets as possible. This depends not only on effective industrial inspection procedures, but on setting a standard of quality which is acceptable to customers and attainable by the manufacturer.

AID TO PRODUCTION

To minimise the amount of faulty merchandise produced, serves to optimise the use of productive capacity for the manufacture of acceptable quality goods. Effective inspection procedures assist in minimising operative irritation and management frustration arising from dislocation of planned production by the interference factor of faults causing delays in the operation cycle.

2.2 GENERAL INSPECTION METHODS

According to Lees (1985), there are three main methods of inspection employed in the production of a garment:

1. 100 per cent inspection.
2. random sampling.
3. statistical.

100% INSPECTION

This method is employed during or after the making-up process and entails inspection of every garment. 100% inspection does not mean every garment is meticulously examined and measured, only that every garment is assessed as being satisfactory or not. Many manufacturers will assess every garment twice - once at the end and once (at least) during the manufacturing process.

RANDOM INSPECTION

This method implies looking at sample batches of garments. It can be calculated from probability laws what percentage of faults are likely to occur in a whole order, from the number of faults that are found in a sample unit. However, this assumes that the batch is random; if the batch is taken from the beginning or the end of a production run then the figures can be misleading. The technique is not normally developed mathematically in the garment industry, but is often used for inspecting work in progress. The principle is that, where fault occurrence is high, the percentage of garments examined is high, but this diminishes as the faults are corrected.

STATISTICAL CONTROL

This technique implies statistical recording of exposed faults, to establish a statistical quality level. The system usually categorizes faults, possibly using the following grades:

a. minor-unimportant faults.

b. major-important faults but still saleable.

c. critical-faults which render immediate markdown or total rejection.

The drawback of this method is the difficulty in establishing hard and fast criteria of acceptance levels. Nevertheless, this method is useful in obtaining a rough idea of manufacturing reliability.

2.3 FABRIC INSPECTION IN THE KNITWEAR INDUSTRY

For many knitwear manufacturers, the costs involved in 100% fabric examination, by traditional methods, are so great it is not economically viable. As a result, it is common for random sampling or statistical quality control techniques to be employed with as little as 5-10% of a production batch forming the test sample.

In considering the variable nature of raw materials, the effect of wear and tear on machinery parts and the way in which changes in the production environment (humidity and temperature) can affect quality of production, defects will undoubtedly occur and randomly within a production batch of fabric. It is, without doubt, advantageous to examine as much fabric, during or after knitting, as possible. In this sense, quality control rests ultimately on efficiency of the inspection system.

The desire for 100 per cent examination of fabric is not newly founded. Based on this idea, many types of devices and inspection equipment have been developed. Traditional fabric inspection systems used in Industry today may be described in terms of inspection during knitting and inspection after knitting.

2.3.1 INSPECTION DURING KNITTING

At the point of production, the knitting machine usually has a facility to allow the operator to inspect the fabric as it is produced. Often, this takes the form of an illumination source, sited inside the frame, over which the knitted tube of fabric passes immediately before the fabric roll-up mechanism forms the fabric roll. This allows the operator to detect knitting defects and to effect adjustments or repairs to the machine. The outcome of this mode of operation serves to minimise recurring knitting defects and to reduce machine down-time due to major faults arising from relatively simple problems. Though this stage of inspection allows the operator to prevent defects from continuing, no attempt is made at this stage to record or remove the faults. Continuous machine stoppages, for this purpose, are not acceptable to the manufacturer as the output from the machine would be drastically reduced. An operator is usually responsible for six or more machines and thus only a random check for repeating defects is conducted. Early recognition of damage to fabric is one reason why some engineers have devoted their total efforts to enhancing the operating efficiency of the jersey knitting machine and to improving the level of ultimate fabric quality. From the knowledge that faulty needles are a major cause of defects in circular knitting, developments have progressed along two separate avenues - specialised yarn feeding and storage systems and needle sensor devices (Knitting International, November 1982).

2.3.1.1 SPECIALISED YARN FEEDING AND STORAGE SYSTEMS

The need for greater regulation of commercial knitting machines is familar to many sectors of the Textile Industry. Advancements have taken place in the sock sector with the development of a microprocessor system to overcome problems of variations in yarn tension causing inconsistencies in sizes and length of the product. Additional benefits include up to 20% saving in yarn, 50% fewer needle breakages and higher quality products using lower quality yarn (Textile Horizons, October 1985). Accepting the basic need of the knitter to achieve greater production economics from circular knitting machines, with secure fabric quality and relatively small capital outlay, yarn feeding and storage systems have attained widespread acceptance by virtue of the ability to make major contributions to machine productivity. Among the claimed advantages from such units are that they facilitate a 15-20% increase in the speed of older machines; approximately 70% reduction in the incidence of machine stops; up to 90% reduction in press offs; greater operator efficiency and a substantial reduction in needle wear (Knitting International, 1982).

2.3.1.2 NEEDLE SENSOR DEVICES

Auxiliary equipment such as needle scanner devices are now evident in Industry (Knitting Times, 1981). The needle scanner checks every needle - both cylinder and dial -

during each revolution of the machine. This technique employs the projection of a small beam of light onto the passing needles. Undamaged needles reflect the light to a receiver in a series of electrical pulses. A missing pulse indicates a broken or distorted needle, the device then has the capability to stop the knitting machine - normally within one revolution. A vital feature is the facility to program the device to record the defect on the first revolution and to stop the machine only if the fault reappears on the second or a subsequent specified revolution. It is estimated that needle breakages occur more frequently as machine speeds increase, needle scanning and defect recording, by optical means, assists in the reduction of certain types of knitting defects and makes possible the statistical evaluation of these defects. Determination of defect frequency can be the deciding factor for economical needle changes.

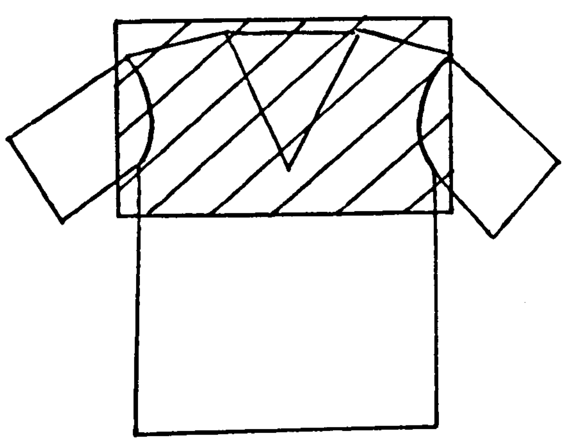
2.3.2 INSPECTION AFTER KNITTING

The inspection of fabric during a post-knitting operation is common practice in the Knitwear Industry. Fabric examination has traditionally been achieved by passing fabric across an inspection frame under the scrutiny of a human inspector (Isett, 1977). Cloth is typically moving at 15 to 40 metres per minute until a defect is observed. Once this occurs, the fabric is slowed or stopped and the defect classified and recorded on an inspection report.

At the end of the roll, it is often the case that manufacturers use the information in the inspection report to assess or grade the roll of fabric. Grading of fabric rolls is not a universal procedure as examination of the fabric alone cannot decide which visible blemishes in the fabric will be counted as faults in the finished garment. Regardless of the severity of the knitting defect, if it fails to fall on a garment panel it is causing no excess cost to the manufacturer. By the same token, a small blemish may cause a garment to be rejected or down-graded in quality if it falls on a sensitive area such as the presentation area of the garment. An example of the presentation area is illustrated in figure 3. Depending on circumstances, up to 15% to 20% of fabric in the lay may not be used in garments (Rae 1974).

FIGURE 3

PRESENTATION AREA OF A GARMENT



2.3.2.1 DEVELOPMENT OF FABRIC INSPECTION TECHNIQUES

Whilst fabric inspection after knitting remains a manual operation, improvements have been made to examination machinery. Many of these changes are closely related to enhancement of the capabilities of the human inspector, the role of whom will be discussed in a subsequent section. The path of developments in examination techniques is shown in figure 4. Excluding automated inspection techniques, all others have a current, widespread application in Industry.

FIGURE 4

DEVELOPMENT OF FABRIC INSPECTION TECHNIQUES

MANUAL

MECHANICAL

SEMI-AUTOMATED

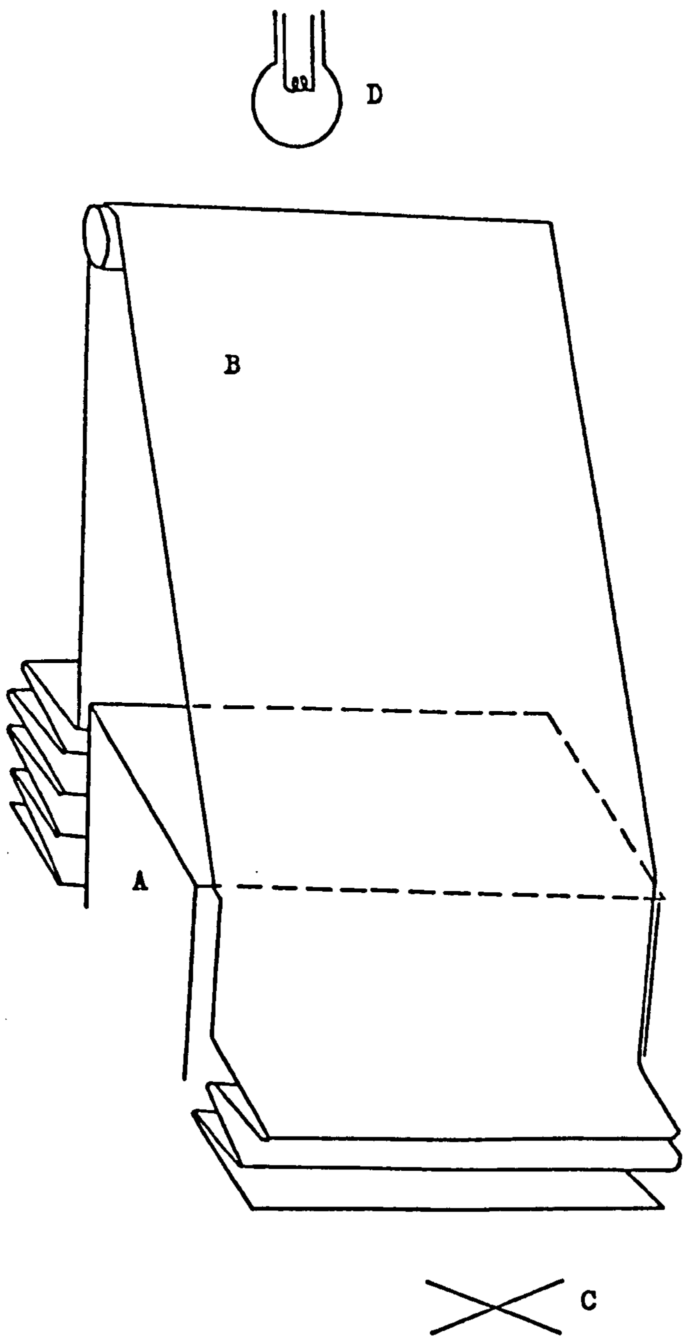
AUTOMATED

2.3.2.1.1 MANUAL TECHNIQUES

One of the earliest known forms of industrial fabric inspection equipment, still is use today, relies heavily on the human inspector for its mode of operation. Figure 5 is a diagrammatic representation of the manual fabric inspection table.

FIGURE 5

THE MANUAL INSPECTION TABLE



A Inspection Table
B Tubular fabric
C Viewing position
D Overhead illumination

A human examiner is positioned in front of a table, above which a pulley system is fixed. The tubular fabric, directly from knitting, is fed over the pulley system and the examiner draws the fabric down, manually, to inspect for faults. Periodically, the examiner will twist the fabric round 180 degrees in order to scan the underside of the tube and then return to the original fabric face before proceeding to a fresh area of fabric. Illumination is positioned above the examination table to facilitate viewing. Faults are registered manually by the examiner on a pre-defined report form.

For change to occur, dissatisfactions are often present in existing operating methods. Early developments in fabric inspection methods have been off-set by the following factors:

1. manual inspection techniques are very slow, permitting 10-15 metres of fabric per minute to be examined.
2. manual recording of faults by the examiner consumes 25% of examination time.
3. a very small quantity of fabric on the underside of the tube is examined.
4. uneven illumination of fabric from an overhead source may conceal certain defects.
5. the consistency of results between examiners may be unreliable as it is difficult to

train examiners to see the same things, in the same way, day in and day out.

6. inspection results are often inaccurate due to the undesirable elements of human nature such as fatigue, loss of concentration, effects of social and environmental pressures, differences in visual acuity and various levels of experience.

2.3.2.1.2 MECHANICAL TECHNIQUES

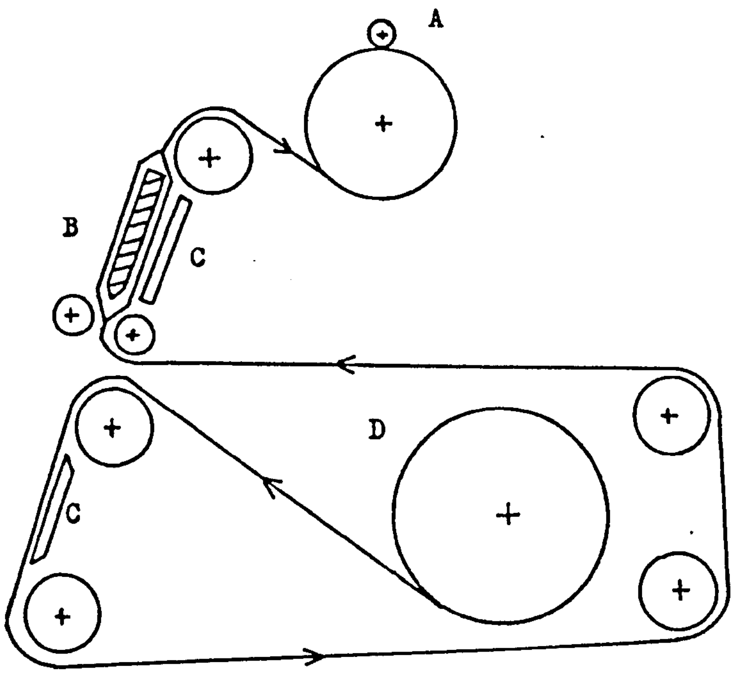
The term 'examination machine' is something of a misnomer, the implication being that the machine does the examining. Friend 1980, suggests that, although devices have been produced which, with varying degrees of success, will detect certain types of faults, the true purpose of the machine particularly those used for open-width examination is, in most cases, to roll and measure fabric and to contribute to an environment in which it can be inspected by an operator. Even with the aid of a motor-driven system for rolling the cloth and moving it past the inspection table, mechanical techniques are still primarily manual (Knoll, 1975) and are perhaps the most common employed by the Knitwear Industry today. Of the many different machines available for inspection of circular fabrics after knitting (Knitting Times, 1979), their characteristics may be grouped into two basic arrangements; roller and mirror.

ROLLER ARRANGEMENT

Figure 6 shows a typical fabric inspection with a roller arrangement. To assist the human inspector in examining the tubular fabric, a stretcher frame is inserted inside the tube which spreads the fabric taut prior to fabric take-up. The fabric is illuminated from behind by fluorescent strip lighting concealed by white perspex sheeting. Both sides of the fabric can be viewed by the operative, although the front and back of the fabric, when viewed, do not relate directly to each other. The inspection machine measures the length of fabric in a roll. This measurement is only approximate as the fabric is under lengthwise tension from the stretcher frame onwards.

FIGURE 6

FABRIC INSPECTION MACHINE WITH ROLLER ARRANGEMENT



A Fabric take-up

B Stretcher frame

C Light

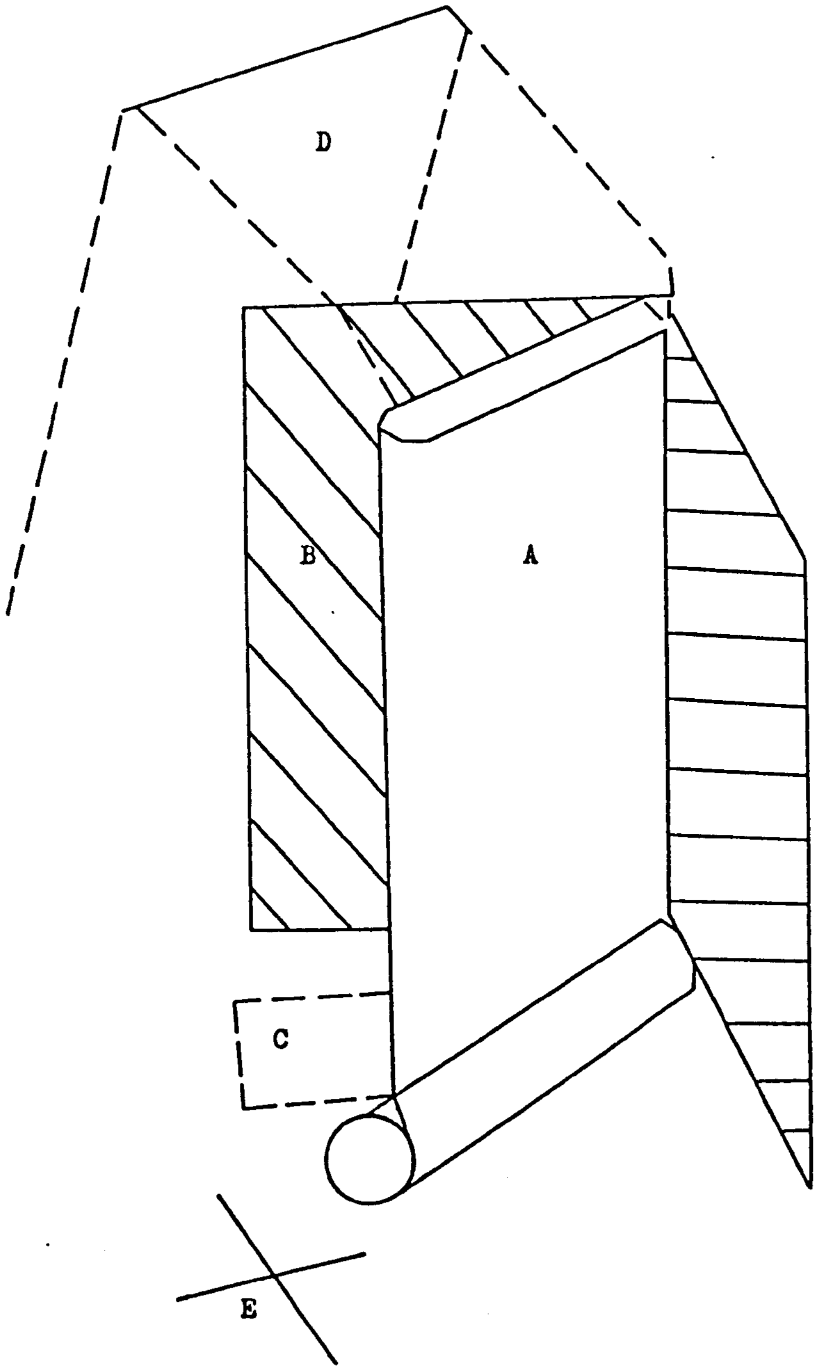
D Fabric

MIRROR ARRANGEMENT

Figure 7 shows a fabric inspection machine with mirror arrangement. A feature of this machine is a through lighting system where tubular fabric passes over a translucent plastic expander. The expander has internal fluorescent lighting tubes powered by microwaves. Both sides of the fabric may be examined simultaneously through the use of a mirror arrangement. The speed control is adjustable by a human inspector's foot pedal.

FIGURE 7

FABRIC INSPECTION MACHINE WITH MIRROR ARRANGEMENT



A Lighted screen, over which tubular fabric is viewed (screen size interchangeable)

B Mirrors

C Metre counter and variable speed control (foot operated)

D Mechanical fabric feed

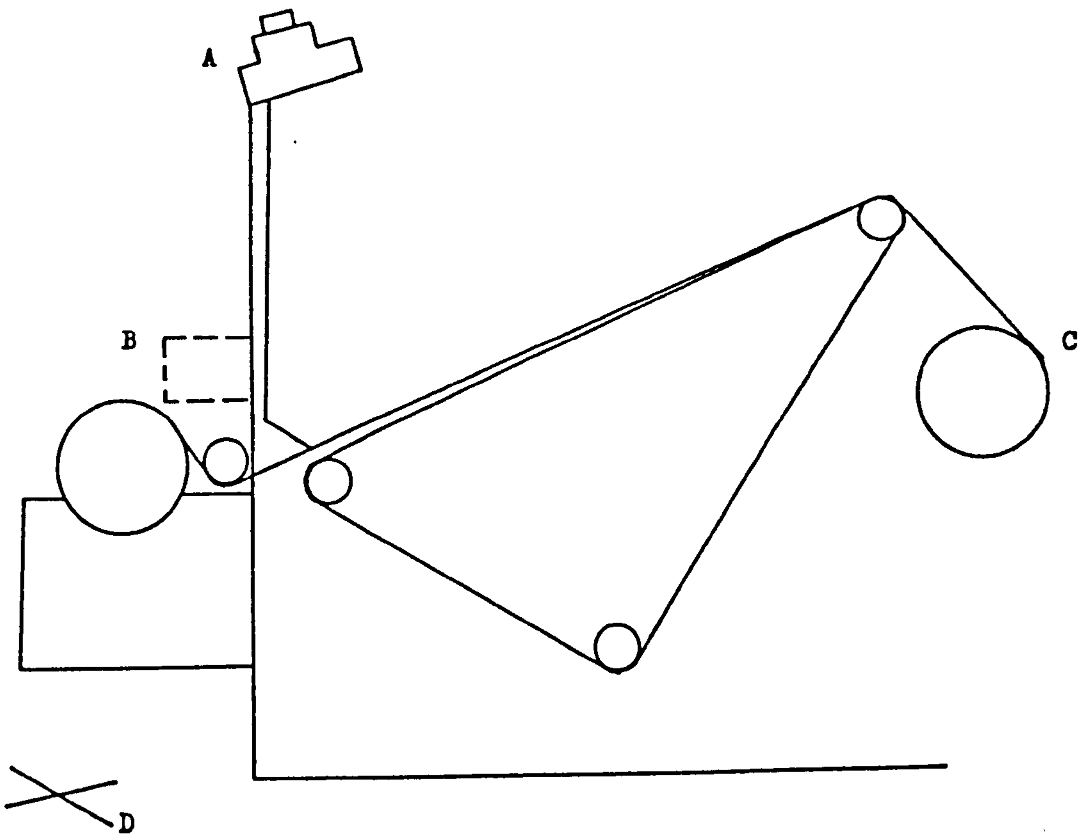
E Viewing position

In both arrangements, significant inprovements serve to enhance the inspection process. These arrangements offer the facility to inspect both sides of the fabric tube, improved illumination and a fabric feed mechanism assists in higher inspection output, up to 25 metres of fabric per minute.

To overcome two basic problems of lack of equipment to handle the variety of fabrics required by changing fashion and low productivity due to manual handling of fabric rolls, a special-purpose inspection system has been developed to integrate the examination and relaxation of knitted fabrics (Haft, 1980; Knitting International, 1984). This system represents a new approach to the inspection of knitted fabrics in so much as it is moving towards a multi-functional system. A feature of the system is that it incorporates a means for relaxing the fabric before measuring, thus allowing a true reading of the measurement even if the fabric has been previously wound on a roller under tension. The system includes a load and unload facility allowing the operation to be completed in a very short time, assisted by a human operator. Inspection can thus be on an almost continuous basis and production increases in the region of 30-50% are claimed. Other machine developments have taken place in fabric inspection equipment where the major application lies in manufacturing processes other than the post-knitting stage. A fabric monitoring system of the type shown in figure 8 is most commonly used to examine open-width fabric after finishing. This system has no facility for viewing both sides of the fabric tube in a single examination of the fabric roll.

FIGURE 8

OPEN-WIDTH FABRIC INSPECTION MACHINE



A Overhead illumination

B Metre counter and variable speed control

C Fabric

D Viewing position

2.3.2.1.3 SEMI-AUTOMATED TECHNIQUES

A viewpoint proposed by Powderly (1981), suggests that fabric quality is improving as a consequence of better equipment, more sophisticated control devices and more automation within the inspection process. Total automation of the inspection process, at any stage of manufacturing, is yet to be realised by the Knitwear Industry.

A number of innovations have been developed in the form of auxiliary equipment to the mechanical arrangements (described in section 2.3.2.1.2). Electronic defect marking and registration systems are now available for aiding the inspector in monitoring and recording pre-defined faults during inspection (Knitting Times, December 1980; Melliand Textilberichte, 1980; Knitting International, January 1982; Textile Horizons, January 1985). Defects which have been detected by the human inspector visually are also visually classified and selected are, by pressing the appropriate button on a hand-held control, automatically registered and also marked if necessary. Defects are fed into the unit in accordance with a previously arranged code number. The units are designed to register up to nine types of defects. The inspector determines which of the faults require registration only and which, in addition, have to be marked. Inspection time and costs are reduced as there is no need for stopping and restarting inspection to record faults manually. If required, the inspection system has the facility to automatically provide a statistical analysis of defects in the form of a printed report. It is claimed that the use of these devices will increase inspection efficiency by over 25% (Textile Horizon, December 1985).

As a result of semi-automated control devices within the inspection system, inspection speeds of up to 40 metres of fabric per minute are achievable (Textile Horizons, January 1986).

2.4 THE ROLE OF THE HUMAN INSPECTOR

Throughout developments in inspection methods, the human inspector has remained the universal agent for fabric examination. The task of the human inspector is not concerned directly with the improvement of quality itself but its maintenance at the standard originally intended and specified. In the early days of industrialised production, the responsibility for quality was placed on the operative. As industrialisation grew and methods of mass production were introduced, formal, structured organisations became predominant. The responsibility for quality tended to be placed entirely on inspection. In a study on dynamic visual inspection, Wentworth and Buck 1982, qualify the role of the human inspector as part of an industrial job of auditing the production quality. Numerous versions of this task exist in the Knitwear

Industry depending on the nature of the fabric or garment to be inspected, the types of faults being checked and the nature of viewing to name a few.

Several studies of the inspection process have attempted to define the role of the human inspector. Colquhoun 1964, and Spitz and Drury 1978, developed similar analytical models to describe the psychological operation known as inspection. Three stages are postulated:

1. detection of discrepancy in the material being examined.
2. judgement - does the discrepancy exceed the limits of tolerance (this involves a comparison between immediate perceptual experience and both memory of previous experiences and a standard for comparison).
3. decision - accept or reject.

The inspector acquires knowledge of the product to be inspected, knowing its characteristics and understanding how these characteristics can deviate from the optimum, and which of these deviations render the product defective. Such deviations from the optimum may occur for more than one product characteristic, e.g. for fabric inspection it is common for the inspector to be searching for a multiplicity of fault types.

It has been suggested by Thomas 1962, that an inspector is constantly matching a mental standard against the materials he is scanning, and any article which does not match this image will be rejected. However, where the article is varying, as is often the case in knitted fabrics, expectation based on a knowledge of the process may play a part since a stable mental picture cannot be constructed.

Harris and Chaney 1969, defined three basic categories of inspection tasks : those involving scanning, measurement and monitoring. Bloomfield 1975, investigated the first of these three categories using data from both search and inspection studies. In inspection tasks, scanning is required when, for some reason, a fault cannot be located immediately. Three main types of inspection task are described that involve scanning : the inspection of simple items, multi-part items or sheets. In the inspection of sheets, the inspector looks at a large expanse of material such as fabric. Further investigations by Bloomfield et al 1974, studied the reasons for difficulties in fault detection. The following three reasons are postulated.

EMBEDDED FAULT. The fault fails to emerge perceptually from its immediate background. The failure being caused by the patterns of the background and the fault combining to obscure the fault.

THRESHOLD FAULT. The threshold fault does not emerge perceptually from its immediate background, the reason now being that there is a very low contrast difference between the fault and the background.

RELATIVE SIZE OF THE FAULT. The fault is clearly distinguishable from its immediate background but remains hard to detect because it is very small relative to the total inspection area.

Various aspects of the role of man in inspection tasks have been explored (Mills and Sinclair, 1976) and the relationships of a very large number of independent factors to the performance of the inspection process studied. According to Harris 1966, optimal organisation of quality control inspection activities and development of procedures and tools to assure satisfactory inspection performance require an understanding of inspector capabilities and of the factors which influence inspector performance.

2.4.1 FACTORS AFFECTING INSPECTION PERFORMANCE

In the Knitwear Industry, the fabric inspection operation is still human mediated and its success is significantly dependent upon the performance, efficiency and reliability of the human operator. People bring eyes, ears, nose, mouth and fingers to the inspection task and with these they can see, hear, smell, taste and touch the objects offered to them. Each of these senses is capable of quite high performance; but each is also prone to certain kinds of error and weakness. From a psychological viewpoint, Drury and Fox 1975, suggest the basic skills of the inspector required for the task have not to be trained to accommodate external structures but are innate and should only require development. Since the consequences of inadequate inspection can be costly in terms of total cost of the production operation, it is not surprising to find that several research studies have addressed the problems in this area (Kochbar, 1980; Oborne, 1982; Megaw, 1983; Noro, 1984).

An examination of human performance in inspection tasks began with an acknowledgment of the fact that humans could well be integrated into quality control schemes. Harris and Chaney 1969, and Drury and Fox 1975, showed how the capabilities and limitations of human operators as quality control inspectors could be determined. Megaw 1979, suggested four groups of factors which could influence inspection accuracy; subject factors, physical and environmental factors, task factors and organisational factors. These factors are shown in table 5.

TABLE 5

FACTORS WHICH COULD AFFECT INSPECTION PERFORMANCE (MEGAW)

SUBJECT FACTORS

visual acuity
eye movement scanning strategies
age
experience
personality
sex
intelligence

PHYSICAL AND ENVIRONMENTAL FACTORS

lighting
workplace
aids - magnification
       overlays
       viewing screen
       closed circuit tv
background noise
background music

ORGANISATIONAL FACTORS

numbers of factors
briefing/instructions
feedback
feedforward
training
selection
standards
time-on-task
shift hours
rest pauses
social factors
motivation
incentives
job rotation

TASK FACTORS

inspection time
paced versus unpaced tasks
viewing area
fault probability
fault conspicuity
product complexity
density of items

Mackenzie (1958), saw the problems of inspector accuracy being associated with three readily identifiable headings;

a. individual abilities.

b. formal organisation including training, ergonomic factors and work instruction.

c. interpersonal and social relations.

He concluded "inspector consistency is affected by poor definition of standards, by lack of instructions and by lack of calibration with one another". This was also suggested by Cavanaugh and Roger 1962.

The social factors affecting inspector accuracy have been discussed in some detail by Belbin 1957, who described a knitwear factory where knitters lost more pay for seconds than for mendable garments. It appears the inspectors were unable to resist pressure from the knitters to classify reject garments as mends as this resulted in the least amount of lost money.

Some of the factors outlined in table 5 and relating to the performance of the human inspector are discussed in more detail in the following sections.

2.4.1.1 INSPECTOR VARIABLES

A review of available literature by Sinclair 1979, showed that inspectors are not 100% efficient. A specific study (Mills and Sinclair, 1976) in a Knitwear company revealed that only 46% of defects were detected by inspectors.

Since, in the majority of cases, fabric inspection is mainly a visually based task, it is reasonable to expect that inspection performance will degrade as the inspectors' visual ability decreases.

2.4.1.1.1 EYESIGHT

Two aspects of eyesight, crucial to an inspector, are visual acuity and the way in which fixations are distributed over the inspection area. Acuity is a measure of the eye's ability to be able to perceive fine detail. The importance of visual acuity to the accuracy of inspection has received much attention in the past (Jacobson, 1953; Bloomfield, 1975, Megaw, 1979). Many of the tests conducted on this variable have not been validated for industrial tasks, consequently the results demonstrate the possession of good acuity does not guarantee that person to be a more efficient inspector, merely that the chances are relatively high.

Other studies have indicated that an important difference between best and poorest performance is length of time which the inspector takes between eye fixations during the search task; eyes scan the visual field as a series of 'jumps' or saccades, rather than a smooth scan (Megaw and Richardson, 1979; Tsao et al, 1979). Apparently, the time available for inspection and the size of product to be inspected govern the search strategies the inspector chooses to use. Fixation duration has been found to increase as the difficulty of discriminating a target increases (Harris, 1966; Bloomfield, 1970).

2.5 SUMMARY

Tracing the developments in current fabric inspection methods serve to highlight the problems encountered with existing processes. The significance of the human inspector is apparent even in the most recent developments. As yet, total automation of the inspection process has not been realised by the Industry.

As the role of the human inspector grows in significance, the factors affecting inspection performance are discussed. In view of the fact that human inspectors do not achieve 100% efficiency and that the essence of the fabric inspection task is dependent on human vision, two crucial aspects of eyesight are considered; visual acuity and eye fixations. These are two of many variables which can influence the inspector and hence fabric inspection performance.

CHAPTER 3

VISUAL INSPECTION TECHNIQUES AND APPLICATIONS

When looms weave by themselves,
man's slavery will end.

Aristotle

3.0 Application of vision systems to the solution of industrial inspection problems is attractive for a number of reasons. Loker (1982) suggests the following four points:

1. standardised inspection performance.
2. reduced costs of inspection.
3. higher levels of inspection.
4. the freeing of operatives from mundane or trivial tasks.

The nature of the problems involved in producing computer based vision systems have attracted a number of researchers applying different techniques. Knowledge of these techniques has now progressed to the point where solutions to industrial problems may be applied. These have become more feasible by the constantly reducing costs and the increasing sophistication of computers. Chapter 3 reviews visual inspection techniques and their application to industrial problems.

3.1 INTRODUCTION

Manufacturing in the Knitwear Industry requires a large variety of activities involving vision, such as alignment, assembly, packaging and inspection. Because many of these tasks are carried out repetitively by human operators for prolonged periods, undesirable elements such as visual fatigue and other factors, described in chapter 2, often limit job performance.

According to Warnecke and Blasing (1980), it is rarely possible for the human inspector to detect more than 70 per cent of errors occurring over an extended period of time. This figure is highly optimistic in comparison to the 46 per cent of faults detected in a Knitwear company (Mills and Sinclair, 1976). Many researchers agree that human beings probably should not have to perform on-line factory inspection tasks (Artley, 1982; Jarvis, 1980).

A survey by West (1985) showed the projected machine vision market in 1985. The biggest segment is inspection. Totalling 80 per cent of the market, inspection can be sub-divided into three categories : verification, confirming an operation has been performed; gauging, making measurements; and flaw detection, identifying blemishes or other irregularly shaped and randomly located imperfections. It is not surprising therefore that automation of manufacturing visual processes, especially inspection is a recent and rapidly growing technology involving contributions from pattern recognition, image processing and artificial intelligence as well as a host of specialised techniques including robotics for moving and manipulating the objects being inspected.

3.2 IMAGE PROCESSING TECHNIQUES

Manipulation of images by digital methods has found application in many diverse fields, ranging from medical diagnostics and military surveillance to broadcast television and pattern generation equipment for commercial artists (Batchelor et al, 1985). Recently, these methods have been applied to problems found in the industrial environment (Sensor Review, Janury 1984; Brook, 1982; LaCoe, 1984). To enhance flexibility in manufacturing, the use of visually controlled robots in assembly systems is becoming a practical reality (Mortimer, 1984; Saraga et al, 1984; Hartley, 1985; Sensor Review; April 1985).

The automatic inspection of textile materials and garments by computer image processing is an area which, as yet, is relatively unexploited. One of the first major considerations of computers in fabric inspection was carried out by Purll (1970). This study provides useful information on the hardware requirements of such a system, although software interpretation was limited since realistic real-time software processing has only recently become viable. Koshimizu (1979) showed that defects could be detected on small samples of fabric with a camera-based system, but does not extend the work to cover full-width fabric.

A laboratory prototype for automatic visual inspection of textile materials and garments has been developed by Hashim et al (1984). Advanced techniques involving computer controlled vision and image processing in the field of knitted textiles have been developed. In response to a need by the Knitwear Industry, a system capable of automatically pairing socks into one of nine size classes has been produced.

Feasibility studies in the use of video pattern recognition methods to replace the human eye in spotting of manufacturing defects in knitted fabric have been approached by the application of a digital storage oscilloscope (Van der Werf, 1985). This technique allows 'freezing' of the camera image for simpler analysis. A charge-coupled device camera is used to scan the textile surface. A treated signal from the computer is then compared with the output from the camera.

There are a wide variety of powerful image processing operations capable of extracting features from an image. Paramount in the context of automated fabric inspection are filtering operations to remove unwanted noise and clutter and edge detection operations to locate edges which form an important characteristic of a defect. With these attributes, image processing techniques are highly desirable to detect and identify defects in knitted textile materials.

3.3 CONTINUOUS ILLUMINATION TECHNIQUES

Continuous illumination systems are based on arrays of photoelectric cells across the width of the passing fabric. These detect faults as the amount of transmitted or reflected light fluctuates as defects pass.

Kok et al (1975), have developed an instrument for research purposes based on this technique. Six samples, ranging from undyed to dark plain jersey fabric were investigated for detection of defects such as barre and streakiness, and irregularities due to structure or chemical composition in fabrics. The results for barre showed considerably better correlation with visual rating than was the case for the 'streakiness' measurements. This technique is, to date, limited in the types of defects that can be detected.

3.4 LASER SCANNING TECHNIQUES

Since the introduction of lighting techniques in the field of automated inspection of sheet materials, the laser has become the most common source of light (Brook et al, 1979; Brook, 1971).

Flying spot scanners are normally employed for the inspection of non-wovens (Bartoszewicz, 1981). These scanners provide signal evidence which, when coupled with digital and analog signal processing capability, provide a wide range of defect processing capability. Automatic laser-scan fabric inspection developments have stimulated considerable interest in recent years (Schicktanz, 1982; Textile Horizons, December 1983; Knitting International, April 1985).

The technique operates by projecting a laser beam, usually from a helium or neon tube via mirrors onto a faceted, rotating mirror. Accuracy is achieved by incorporation of a traditional fan beam configuration which holds the beam at a constant angle to the material surface. In consequence the size of the projected light spot does not fluctuate allowing defects, located anywhere on the material surface to be evaluated equally. Underneath the fabric sheet, photomultipliers pick up the transmitted light and their summed output contains 'peaks' whose amplitude and duration indicates the defect size and shape. Severity of defects can be classified by accumulation of amplitude information from successive scans and the application of quantizing electronics which capture and track a defect.

Using this technique, a system is capable of high accuracy, at speeds in excess of 100 metres of fabric per minute, over the full scanning width of the web. In conventional visual inspection, Schicktanz (1984) estimates that one person can cope on average with 600-800 metres/hour. Inspection capacity using a laser scan system is estimated to be capable of 6120 metres of fabric/hour.

3.5 EXPERT SYSTEMS

Expert systems are attracting much attention today as they represent a new approach to computer applications, drawing upon artificial intelligence techniques developed in the past two decades. Of the many papers published in this field, human expertise is the central core of the expert system (Fox, 1982; Kidd, 1983).

Addis (1982) reports one viewpoint which states that human approaches to problem solving should obey the rules of logic and that any deviation from these rules is unacceptable. However, much of human behaviour lies outside the domain of standard logic and this includes the intellectual ability of an expert within a field of endeavour. It is this kind of expertise that knowledge engineers are trying to capture for expert systems in order to simulate the essence of experts' skills.

In expert systems, tasks are tackled by finding out, and then copying the way they are performed by human experts, rather than by analysing the task and subsequently working out a procedure or algorithm for performing the task. To encapsulate specialist knowledge of a human expert, an expert system requires three distinct components:

a. A KNOWLEDGE BASE - This may be generally described as a database with added rules.

b. AN INFERENCE ENGINE - A program capable of carrying out logical inferences in an intelligent manner.

c. A USER INTERFACE - This enables the user to interact with the expert system.

According to Feigenbaum, an originator of the "expert system" method of programming, the new computers will "emulate and sometimes exceed the behaviour of the best human professionals". The major advantage of this new approach is that computing power can be brought to bear on tasks that defy adequate analysis because they are too complex or ill-defined.

These developments have now opened up areas for exploitation within industry. The techniques provide means for building characteristics into computer-based systems that, to some extent, emulate those of human experts. From his research, Ueno (1983) found that performance of such systems depends mostly on the amount and quality of the knowledge extracted.

To demonstrate the usefulness of expert systems, a survey has been conducted of the range of fields where they have already been applied.

3.5.1 INDUSTRIAL APPLICATIONS OF EXPERT SYSTEMS

Expert systems operate particularly well where the thinking is mostly reasoning and not calculating. This incorporates vast areas of the worlds work. A survey by Fox (1985) of applications of expert systems includes the following:

medical diagnosis (various kinds)
advice on social security benefits
assessment of entitlement to British Citizenship
corrosion analysis
packaging advice
fault diagnosis
computer performance prediction

Perhaps the largest single group of expert systems is centred in medicines. At Stanford University, several expert systems have been designed mostly in the area of diagnostics. Whilst these systems have been reviewed elsewhere (Addis, 1980; Addis, 1982; Feigenbaum and McCorduck, 1983), Mycin has received much attention in publications. Mycin diagnoses blood and meningitis infections, then advises the physician on antibiotic therapies for treatment. Like other expert systems, Mycin acts as a consultant having a conversation with its user, the physician.

Basden and Kelly (1982) have developed a prototype expert system to predict the risk of stress corrosion cracking. Similar lines of research have been conducted in Japan in development of an expert system for damage assessment of existing structures (Ishizuka et al, 1982; Ishizuka, 1984). From this research, significant in roads have been made in the use of expert systems for fault diagnosis. The literature search has revealed that the majority of research into fault diagnosis lies in material engineering, with no evidence of a similar application in any aspect of knitted textiles.

3.5.2 KNOWLEDGE-BASED COMPUTER VISION TECHNIQUES

In a review of activities concerning expert systems in Japan (Ishizuka, 1984), integration of image processing and expert system techniques is a recent approach under investigation. There are several ways in which expert systems can contribute to image understanding. Firstly, since a systemmatic integration of a lot of knowledge and an efficient search mechanism is important in the design of advanced model-based image understanding mechanisms, a similar approach to expert systems becomes necessary. Secondly, the combination of knowledge and image processing technologies will bring advanced expert systems into industrial and professional vision and image applications. Besides medical applications, knitted textile inspection is an operation which uses the expertise of the human examiner to understand and analyse the image of the knitted fabric which the eye produces. Development of a knowledge-based computer vision system for inspection of knitted fabrics will be discussed in the ensuing chapters.

3.6 SUMMARY

Use of vision systems for the solution of industrial vision problems has received much attention in recent years. Image processing is a technique which is proving highly desirable to the inspection of textile materials. Powerful image processing operations are capable of reducing background noise and extracting features from an image. Two factors which are very important to the detection and identification of defects in textile materials.

Expert systems have been successfully applied as consultants to the human expert in several fields. These systems have advantages of greater memory capacity for storing facts and the ability to form logical deductions based on information in a knowledge base.

Integration of these two powerful techniques represents a new and highly attractive approach to the solution of industrial inspection problems such as fabric inspection. Other techniques tend to be limited in their application due to high costs involved in laser scanning and restricted types of defects that are detectable using illumination techniques.

CHAPTER 4

SYSTEM SPECIFICATION AND STRATEGY

There are only two qualities in the world: efficiency and inefficiency; ....

G. Bernard Shaw

4.0 Automation of inspection is a necessity not only because of the need to integrate inspection into automated manufacturing, but also because it is viewed as the only means of meeting the demand for higher quality through 100% verification of products or sub-products. Development of an industrial vision system for the automated inspection of knitted fabric requires a knowledge of manufacturing requirements and quality standards of the product. Chapter 4 discusses the industrial requirements of fabric inspection that form the basics of a system specification and strategy for development of the system.

4.1 INTRODUCTION

With the ever-increasing use of computers in all facets of industry, computed-aided inspection is a growing field. As with any other industrial projects, there must be economic justification for implementing an automatic inspection scheme. Brook (1979) outlines several situations in which there is likely to be sufficient incentive:

1. where there is off-line inspection of items leading to delay in detecting poor quality and hence risk of producing large quantities of faulty material.
2. where there is high added value at each stage of the process and it is therefore important that faulty material is not inadvertently processed.

3. where a large volume of material is produced at high speed.
4. where inspection is needed as part of a large overall integrated automation programme.
5. where safety depends on the quality of the product.
6. where there are contractual penalties associated with failure to meet quality standards.
7. where the amount of material or energy used per unit price charged can be reduced.

Justifying automatic inspection for a specific purpose is an important first step as there is a strong tendency for automation to be regarded as a major weapon in times of pressure on costs.

In the production of knitwear garments, costs and quality are principal factors. It is not possible to adequately differentiate their relative degrees of importance to the success of automated inspection. Quality is a major factor for two basic reasons. First, like price, it acts as a competitive variable and second, it can be used as a direct marketing tool in that a significant change in quality can differentiate the product from others - serving to reduce the number of direct competitors.

The application of automation to the fabric inspection process draws closer to realisation as the costs of computer equipment continue to decrease.

4.2 INDUSTRIAL REQUIREMENTS

Inspection seeks to ensure compliance with customer expectations of what a product should be. Product reliability, interchangeability, conformity, compatibility and acceptability are all cited as examples of customer expectations.

The quality level of the product is determined by two factors; quality of design and quality of conformity to the design. Quality of design is not the major criterion as manufacturing on a mass scale does not commence until the quality of design is agreed with the customer. During production, conformity is the major requirement. Good quality of conformity means that the product will be a reasonable replica of the original sample purchased by the buyer. Part of the process of achieving conformity of products to the original sample is the use of standards for operatives and inspectors to work to.

Computers should play an essential role in quality control by performing inspection tasks at fast speeds with an exceptionally high degree of accuracy.

An initial step in machine displacement of human professionals is standardisation of the professionals knowledge and methodology. For consistent and reliable fabric inspection the following quality parameters are required of an automated system:

1. 100% detection of defects which cause excess cost to the manufacturer.
2. it is highly desirable for the system to identify the defects.
3. information feedback to the knitting area for remedial action at source.
4. system flexibility to accommodate varying quality levels.
5. monitoring of efficiency of the system to ensure improved performance.

4.2.1 DEFECT DETECTION

The most important aspect of the quality of fabric is its freedom from faults. The faults which are of interest to the manufacturer are those which increase the cost of garment production and adversely affect sales. A major industrial requirement of an automated inspection system is that all fabric defects are detected. A viable automatic inspection system cannot be specified based on a few "typical" or "average" defects. A thorough feasibility study is required involving examination of a significant number of defective garments. A study of defective garments as opposed to a study of defective fabric is proposed for the following reasons:

1. the customer purchases a garment on the basis of the finished item and its performance under certain conditions.
2. fabric in its raw state cannot be compared to

the end-use fabric, having undergone several rigorous processes of dyeing and finishing, make-up and pressing. Apparent defects which appear in the fabric during knitting may not necessarily adversely affect the end product. An oil stain, occurring during knitting, may be effectively removed or sufficiently masked in subsequent processes and so retaining the required fabric quality.

4.2.2 DEFECT IDENTIFICATION

Whereas defect detection involves the location of a fault, with no further knowledge assigned to the fault, defect identification encompasses the definition of a set of visual features by which a specific fault can be recognised. To incorporate identification into an automated fabric inspection system, a defect classification is a prerequisite for the quality specification. Defect identification is desirable for the following reasons. Firstly, for regular feedback of quality performance to operatives and, secondly, it provides a means of ensuring that the output quality is under control.

4.2.3 INFORMATION FEEDBACK

A defect is an outward sign or indication of an abnormality in processing conditions at a given point in the manufacturing process. In a manufacturing environment such as jerseywear production, it is not sufficient to identify the defect. Depending on the capacity of the company and the type of garment manufactured, it is possible to output thousands of garments per day. Therefore, once a defect is located, defect information feedback to the source is essential. Depending on the nature or cause of the defect, the quantity of fabric affected ranges from an isolated occurrence to widespread, multiple occurrences. To accommodate the inconsistency in defect occurrence, the decision to feedback information to the source must be a statistical one, based on a defect occurring a pre-determined number of times or over a specified length of fabric. An industrial requirement of automated inspection is an interactive system, capable of supplying information on the cause of defects and remedial actions at source.

4.2.4 SYSTEM FLEXIBILITY

Quality may be defined as a 'degree of excellence'. The degree is determined by subjective assessment: what is satisfactory for one person is not necessarily satisfactory for another. The personal assessment of quality is conditioned by two factors:

1. the shopping environment - a marketing problem.
2. the product itself - a buying and manufacturing problem.

Surveys on customer opinions about quality show that their perceptions are not consistent and are not always related to the true quality standard of the product. To accommodate changes in and adjustments to quality levels, it is important for an automated system to be flexible and easily adapted to changing inspection criteria.

4.2.5 EFFICIENCY MONITORING

The potential benefits of automatic inspection include reduced labour costs, improved yield, increased capacity, and improved and consistent quality. To consider automatic inspection's impact in terms of efficiency and performance depends greatly on the systems ability to detect and recognise specific defects. To obtain a measure of performance requires statistical knowledge of the significance of each defect. The significance of each defect is directly related to the performance of the system, as where a high percentage of defect occurrences are attributable to one type of defect then the system's ability to detect that defect provides a relative performance measure.

4.3 THE WAY FORWARD

The requirements of an automated fabric inspection system are summarised as follows:

1. the acquisition, standardisation and incorporation of human inspector expertise.
2. an interactive capability through which information feedback and feedforward takes place.

3. system flexibility to adapt to changing quality and inspection criteria.
4. system performance evaluation.

The problem of automating the fabric inspection process with conventional computer systems has remained unsolved. With the advent of thinking, reasoning systems, knowledge-based techniques are beginning to yield systems with far greater abilities than traditional computer programs. The key concept which distinguishes expert systems from their mathematical and algorithmic predecessors is the explicit use of knowledge.

The current approach to fabric inspection relies heavily on human expertise: the ability to identify and synthesise diverse factors, to weigh evidence, to form judgements, to evaluate alternatives and to make decisions. To automate fabric inspection, a system is required which is designed to embody the specialised knowledge and experience of the human expert together with sophisticated problem-solving mechanisms. On this basis, the development of an expert or intelligent knowledge-based system is proposed in response to the needs of Industry for an automated fabric inspection system.

4.4 SUMMARY

The success of an automated fabric inspection system depends on its applicability to the industrial setting for which it is intended. Chapter 4 establishes the major requirements of such a system and examines the suitability of computer techniques for development of a system. As a result of these findings, the approach adopted for the research incorporates the development of an intelligent knowledge-based inspection system.

CHAPTER 5

DEFECT CLASSIFICATIONS

I have taken all knowledge to be my province.

Francis Bacon

5.0 Research by Wira (1970) and the Shirley Institute (1971) has shown that the UK Clothing Industry loses tens of millions of pounds each year owing to fabric faults, resulting in reject garments. Clearly, there is a strong incentive to investigate faults with a view to reducing these losses. Chapter 5 contains a review of literature on defect classifications and a survey of defects in single jersey and 1 x 1 rib, cotton fabrics. The results of the survey are presented in defect classification form. Three approaches to the development of a classification scheme are described.

5.1 INTRODUCTION

Numerous attempts have been made to construct classifications of defects. These, for the most part, have involved the accumulation and clarification of the many terms that have come into common use over the long history of the Textile Industry. The comprehensive assignment of textile terms to defects can cause confusion and complicate defect detection and identification during the fabric inspection process.

5.2 REVIEW OF DEFECT CLASSIFICATION SCHEMES

The oldest classification system is known as "the 10 Point System" (1955). This scheme was designed to identify defects and to assign a value to each defect based upon its severity. In 1959 a "4 Point System" for fabric quality was proposed by the American Society for Quality Control.

This scheme is similar to the "10 Point System" in awarding penalty points but does so on a different basis. In comparing the two systems, there is a tendency for the "4 Point System" to classify more fabric as "firsts". A variation of the "4 Point System" was published in 1971 by the Textile Distributors Association. This system was proposed specifically for knitted fabrics as opposed to other multi-purpose systems which included warp and weft knitting as well as weaving.

The Graniteville System (1975) has been used by several major mills and clothing manufacturers. A feature of this system is the identification of major and minor defects. A major defect is one which, if in an exposed position, will cause the finished product to become a second. A minor defect is one which is not visually obvious due to its location in the end-use item.

In contrast to the general classifications described, certain companies have found established classification schemes inappropriate for their particular product or mode of operation. One such company West Point Pepperell (U.S.A.) has developed its own manual for the purpose of providing a systemmatic and uniform approach to the identification and grading of the most common flaws found in knitted fabrics. Although the manual has been constructed to satisfy the specific needs of the knitting division within the company, good judgement and experience are required in reaching decisions on defect severity.

In 1976, yet another variation of the point system was proposed by an advisory panel set up by the Clothing Institute. The scheme concerns itself with the classification of fabric quality according to the faults contained. The point system employed differs from that originally proposed by the American Apparel Manufacturers' Association (1962) in that it has metricated.

The point systems currently in use are similar to each other in that they are based largely on traditional methods in the Industry. It is noteworthy that these schemes do not provide an adequate basis for determining the true cost of defects. Difficulties then arise for garment manufacturers in making optimum accept/reject decisions at the fabric inspection stage.

Knoll and Wolfe (1975) described a point system for fabric grading in which the points assigned to faults are a function of the material being inspected and the garments to be produced from the fabric. The points relate directly to the size and shape of the panels to be cut from the fabric. The accumulated points for a roll of inspected fabric represent the number of faulty panels resulting from that roll. Since increases in production costs due to faults can be directly related to the number of faulty panels an objective accept/reject decision can be made on the basis of the accumulated point total.

In 1970, Wira followed a different approach to the classification of defects by investigating the effect and cost of fabric faults in garment manufacture: shirts and rainwear. The Shirley Institute (1971) continued this line of research in the field of ladies' and mens outerwear. The report suggests ways in which the cost of major faults can be reduced.

More recently, the American Society for Testing of Materials (1981) published the standard definitions of terms relating to fabric defects. This standard incorporates many of the terms which are currently used industrially to describe defects.

Sweranowsky (1982) constructed a defect classification specifically for circular knitted fabrics. The common knitting imperfections were reduced to the following types:

1. VERTICAL LINES
2. HORIZONTAL LINES
3. DROPPED STITCHES
4. CUTS AND HOLES IN FABRICS
5. UNWANTED TUCK STITCHES

The classification also covers a series of "less frequent" and isolated faults.

A renewed interest in the point system has been shown by the British Standards Institution (1983). Under B.S 6395 a method is described for the numerical designation of faults in finished fabrics by visual inspection and provides a means of indicating the position of faults.

5.3 SURVEY OF DEFECTS - SINGLE JERSEY AND 1 X 1 RIB COTTON GARMENTS

Of the defect classification manuals available, many cover the wide spectrum of textile defects from various sectors of the Industry. Just what is a 'fault' has been a subject of much debate. Wira (1973) conducted a survey in Great Britain to extract the views of the clothiers concerning faults. A range of attitudes towards the definition of a defect were displayed. The following comments encompass the range of views:

1. a fault is any imperfection which could cause dissatisfaction in appearance or in functions in wear, or loss or disruption in production, or prevent the garment being sold at full price.
2. the clothing trade is not concerned with the source of the fault, merely its effect. Three classifications are possible:
   a. a MAJOR FAULT - one which cannot be allowed to appear in the garment.
   b. a MINOR FAULT - one which may appear in an unobtrusive area of the garment.
   c. a TECHNICAL FAULT - one which a clothier would not include as a fault.

3. what constitutes a fault depends on the quality and price of the fabric and garment involved.

A criterion underlying all three definitions is one of defect cost. Differing markets make different calls on fabric perfection. That which is classified a fault when it appears in isolation in one fabric may not be considered a fault when it appears throughout another fabric where it becomes an integral part of fabric character.

The approach adopted for the research aims not to establish new fault definitions but to capture the commercial standards involved when accept/reject decisions are made regarding jerseywear garments. The aims of the survey are described as follows:

1. to determine those defects specific to single jersey and 1 x 1 rib, cotton fabric.
2. to determine only those defects which cause excess cost to the manufacturer.
3. to determine the significance of each type of defect in terms of its frequency of occurrence.

To achieve these aims, the survey was conducted at the final inspection stage in the production of jerseywear garments.

5.3.1 METHOD OF APPROACH

Investigations were conducted in five companies - all manufacturers of cotton jerseywear. Manufacturers details are shown in table 6. This information is privy to each of the companies that contributed to the survey therefore the companies are coded A-E.

TABLE 6

COMPANY DETAILS

COMPANY CODE	A		b		C		D	E	
GARMENT	underwear + childrens sleepwear		underwear + leisure		underwear + leisure		underwear	underwear + leisure	
%FABRIC INSPECTED AFTER KNITTING	SJ	DJ	SJ	DJ	SJ	DJ	DJ	SJ	DJ
	10	10	50	10	100	5	5	0	0
METHOD OF FABRIC INSPECTION	1		2 & 4		3		3	-	

DETAILS OF FABRIC INSPECTION METHODS SHOWN IN APPENDIX A

Over 10,000 reject garments of the types outlined in table 6 were examined. The faults observed were recorded and the breakdown of numbers of garments examined in each company is shown in table 7. The variations in numbers examined in each factory was largely due to differing throughout rates at the time of the survey. The throughput rates were influenced by the sizes of the companies involved.

TABLE 7

BREAKDOWN OF TOTAL NUMBER OF GARMENTS EXAMINED

COMPANY	A	B	C	D	E	TOTAL
SINGLE JERSEY	1626	460	1827	-	691	4604
1 X 1 RIB	495	1963	2140	1148	-	5746
TOTAL	2121	2423	3967	1148	691	10350

5.3.2. RESULTS OF SURVEY

The results of the survey are shown in tables 8-11. Faults are not categorised into major and minor faults but are recorded in order of statistical significance.

TABLE 8

BREAKDOWN OF 1 X 1 RIB GARMENT DEFECTS

FAULT	NO.OCCURRENCES OF FAULT A	B	C	D	E	TOTAL	SIGNIFICANCE (%AGE.)
PRESS OFF	0	192	384	213	0	789	21.0
PRESS OFF 1 BED	126	236	0	172	0	534	14.2
SLUB>=1CM.	51	215	91	160	0	517	13.8
SLUB HOLE	3	74	254	64	0	395	10.5
DROPSTITCH RUN	0	137	150	96	0	383	10.2
NEEDLELINE	72	149	42	47	0	310	8.3
DROPSTITCHES	7	120	124	18	0	269	7.2
BARRE	19	75	92	4	0	190	5.1
KNOT HOLES	4	47	70	8	0	129	3.4
TUCK NEEDLE	0	4	2	56	0	62	1.6
FIBRE CONTAMINATION	3	7	14	33	0	57	1.5
RIP NEEDLE	0	30	15	6	0	51	1.4
KNOTS	7	20	5	2	0	34	0.9
THICK/THIN	0	3	19	2	0	24	0.6
NEPS	0	0	7	0	0	7	0.27
WRONG YARN	0	1	0	0	0	1	0.03
TOTAL	292	1310	1269	881	0	3752	65.3
STAIN	67	142	177	84	0	470	
GLAZING	0	0	239	0	0	239	
DYEING	7	12	92	0	0	111	
PRINT MARK	64	0	0	0	0	64	
TOTAL	138	154	508	84	0	884	15.4
MAKE UP SEAM	38	380	116	39	0	573	
CUTS	0	95	209	111	0	415	
SHADED	0	21	38	4	0	63	
SNAGS	27	3	0	0	0	30	
CUTTING	0	0	0	29	0	29	
TOTAL	65	499	363	183	0	1110	19.3

TABLE 9

SIGNIFICANCE OF DEFECT OCCURRENCE
AT DEFINED MANUFACTURING STAGES

1 X 1 RIB

COMPANY	KNIT FAULTS(%)	DYEING FAULT(%)	M/U FAULT(%)
A	59.0	27.9	13.1
B	66.7	7.8	25.4
C	59.3	23.7	17.0
D	76.7	7.3	15.9
E	0	0	0
OVERALL %AGE.	65.3	15.4	19.3

TABLE 10

BREAKDOWN OF SINGLE JERSEY GARMENT DEFECTS

FAULT	NO. OCCURRENCES OF FAULT A	B	C	D	E	TOTAL	SIGNIFICANCE (%AGE.)
SLUB HOLE	124	17	64	0	154	359	24.1
PRESS OFF	31	65	96	0	105	297	19.9
NEEDLELINE	154	8	122	0	4	288	19.3
FIBRE CONTAMINATION	19	1	11	0	86	117	7.8
THICK/THIN	58	0	35	0	17	110	7.4
BARRE	31	14	23	0	3	71	4.8
DROPSTITCHES	2	10	6	0	42	60	4.0
SLUB>=1CM.	33	8	16	0	2	59	3.9
DROPSTITCH RUN	23	3	15	0	8	49	3.3
KNOT HOLE	26	2	3	0	13	44	2.9
NEPS	16	0	0	0	0	16	1.1
TUCK NEEDLE	0	0	1	0	10	11	0.8
KNOTS	0	1	5	0	1	7	0.5
RIP NEEDLE	0	3	0	0	0	3	0.2
TOTAL	517	132	397	0	445	1491	32.5
STAIN	212	38	87	0	90	427	
DYEING	0	0	19	0	28	47	
TOTAL	212	38	106	0	118	474	10.3
M/U SEAM	480	138	817	0	46	1481	
PLEAT SEAM	218	0	216	0	0	434	
CUTS	0	150	165	0	49	364	
BOUGHT FABRIC	171	0	5	0	0	176	
CUTTING	0	0	107	0	0	107	
SHADED	0	0	0	0	33	33	
DIRTY SEAM	28	0	0	0	0	28	
SNAGS	0	2	1	0	0	3	
TOTAL	897	290	1311	0	128	2626	57.2

TABLE 11

SIGNIFICANCE OF DEFECT OCCURRENCE
AT DEFINED MANUFACTURING STAGES

SINGLE JERSEY

COMPANY	KNIT FAULTS(%)	DYEING FAULTS(%)	M/U FAULTS(%)
A	31.8	13.1	55.1
B	28.7	8.3	63.0
C	22.0	5.8	72.2
D	0	0	0
E	64.4	17.1	18.5
OVERALL %AGE.	32.5	10.3	57.2

5.3.3 DISCUSSION OF RESULTS

Common to all the larger fabric and garment manufacturers is some form of fabric inspection. The inspection method employed and the quantity of fabric inspected varies from company to company. Table 12 summarises the information in tables 6 and 11.

TABLE 12

EXTRACTS OF INFORMATION FROM TABLES 6 AND 11

	COMPANY A	COMPANY B	COMPANY C	COMPANY D	COMPANY E
TYPE OF INSPECTION	ROLLER ARRANGEMENT	MANUAL + MIRROR ARRANGEMENT	OPEN-WIDTH	OPEN-WIDTH	NONE
% REJECTS DUE TO KNITTING DEFECTS - 1 X 1 RIB (% FABRIC EXAMINED)	59 (10)	66.7 (10)	59.3 (5)	76.7 (5)	-
% REJECTS DUE TO KNITTING DEFECTS - SJ (% FABRIC EXAMINED)	31.8 (10)	28.7 (50)	22.0 (100)	-	64.4 (NONE)

An overview of the percentage reject garments attributable to knitting (table 12) shows that, for the most part, the 1 x 1 rib figures are considerably higher than those for single jersey. In the main, the two fabric types fall into two garment categories:

1. 1 x 1 rib for vests and tops.

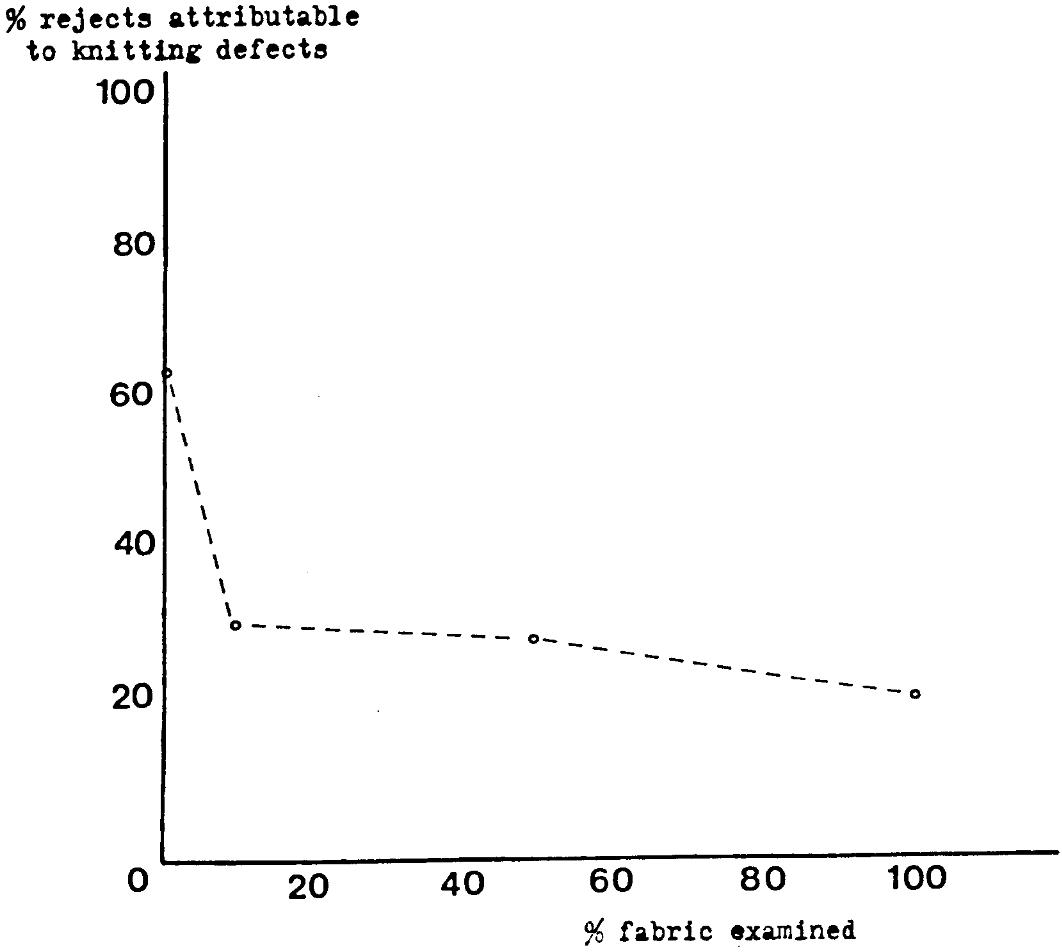
2. single jersey for mens slips and ladies briefs.

Vests and tops contain large quantities of fabric with basic make-up operations involved. Slips and briefs contain much smaller quantities of fabric, compared to vests, with relatively complex elastication operations in garment make-up.

From the survey of single jersey reject garments the results indicate that the greater the quantity of fabric inspected after knitting, the fewer the reject garments attributable to knitting defects, see figure 9. At the same time, for a greater inspection effort the corresponding reduction in reject garments attributable to knitting defects is disproportionate. Where manufacturers employ traditional inspection methods the determination of the optimum level of fabric inspection is recommended. This level is determined by the actual cost to the company which is the sum of the costs of inspection and of poor quality. Whilst it is accepted that there are many factors which influence inspection performance, the quantity of fabric inspected after knitting is highly significant. The results of the survey for 1 x 1 rib from companies C and D indicate that inspection of less than 5% of fabric after knitting is insufficient as a 17.4% increase in reject garments attributable to knitting defects occurs. The order of significance of defect occurrence in 1 x 1 rib bears no relation to the results for single jersey fabric. Such an outcome is not unexpected since the two fabrics are constructed differently.

FIGURE 9

GRAPH OF % S.J. REJECTS ATTRIBUTABLE TO
KNITTING DEFECTS AGAINST % FABRIC EXAMINED



As part of the specification for the development of an automated fabric inspection system, the knowledge-base of defect statistics must be readily adaptable or interchangeable to accommodate inspection of a range of fabric constructions. This is reinforced by individual results from each company which show that, for one fabric type, the significance of defect occurrence varies from company to company. Clearly, for optimum performance in an industrial application, an automated system requires a knowledge-base based on the defect statistics of the user as opposed to a universal knowledge-base based on an accumulation of data.

Tables 8 and 10 list the knitting defects in order of magnitude for 1 x 1 rib and single jersey fabrics respectively. The significance is obtained from the sum of individual defect occurrences within each company. It is acknowledged that by this method a universal defect order is established for both fabric types. For the purposes of the present research, summation of the results from four companies provides a realistically large sample from which the defect statistics are established and the resultant order is unbiased towards any one of the contributing manufacturers.

5.4 DEVELOPMENT OF A DEFECT CLASSIFICATION SCHEME

Using the results of the survey (table 13), the following three approaches to the classification of defects have been developed:

1. Feature Tree Approach

2. Numerical Description Approach

3. Technical Structure Approach

5.4.1 FEATURE TREE APPROACH

Most defects can be located and identified by means of their visual features and characteristics. In considering the most appropriate method of presenting a classification of defects for integration with an automated inspection system, the defects are grouped by their similarities and effect on visual quality of the fabric. Differentiation of defects within a group or type is achieved by extraction of salient defect features. To develop a classification based on the visual features of defects it is desirable to have an easily understood but precise glossary of terms. This minimises the possibility of ambiguity or misinterpretation during the recognition process.

The types of defects and terminology used to describe features of the defects have been determined from literature and an industrial survey. Examples of defects are shown in appendix B.

TABLE 13

SUMMARY OF RESULTS

1 X 1 RIB DEFECT (% OCCURRENCE)		SINGLE JERSEY DEFECT (% OCCURRENCE)	
PRESS-OFF	(21.0)	SLUB HOLE	(24.1)
PRESS-OFF 1 BED	(14.2)	PRESS-OFF	(19.9)
SLUB >= 1 CM.	(13.8)	NEEDLELINE	(19.3)
SLUB HOLE	(10.5)	FIBRE CONTAMINATION	(7.8)
DROPSTITCH RUN	(10.2)	THICK/THIN	(7.4)
NEEDLELINE	(8.3)	BARRE	(4.8)
DROPSTITCHES	(7.2)	DROPSTITCHES	(4.0)
BARRE	(5.1)	SLUB >= 1 CM.	(3.9)
KNOT HOLE	(3.4)	DROPSTITCH RUN	(3.3)
TUCK NEEDLE	(1.6)	KNOT HOLE	(2.9)
FIBRE CONTAMINATION	(1.5)	NEPS	(1.1)
RIP NEEDLE	(1.4)	TUCK NEEDLE	(0.8)
KNOTS	(0.9)	KNOTS	(0.5)
THICK/THIN	(0.6)	RIP NEEDLE	(0.2)
NEPS	(0.27)		
WRONG YARN	(0.03)		

5.4.1.1 DESCRIPTION OF DEFECTS AND DEFECT TYPES

Initially, a large selection of visual features were extracted from available literature. The first classification stage develops as the defects may be grouped into one of four types; VERTICAL, HORIZONTAL, REGIONAL OR DISPERSED.

TYPE : VERTICAL

The fault occurs in a walewise direction (figure 10) where a wale forms a column of loops along the length of the fabric. The defect is continuous in that it extends over two or more consecutive courses. The defect takes the form of a line, the narrowness of which is determined by the number of consecutive wales affected.

DEFECT : DROPSTITCH RUN

A continuous, narrow, vertical line of unformed stitches. A short, horizontal bar occurs in place of each unformed stitch so that a ladder-like effect is created.

DEFECT : NEEDLELINE

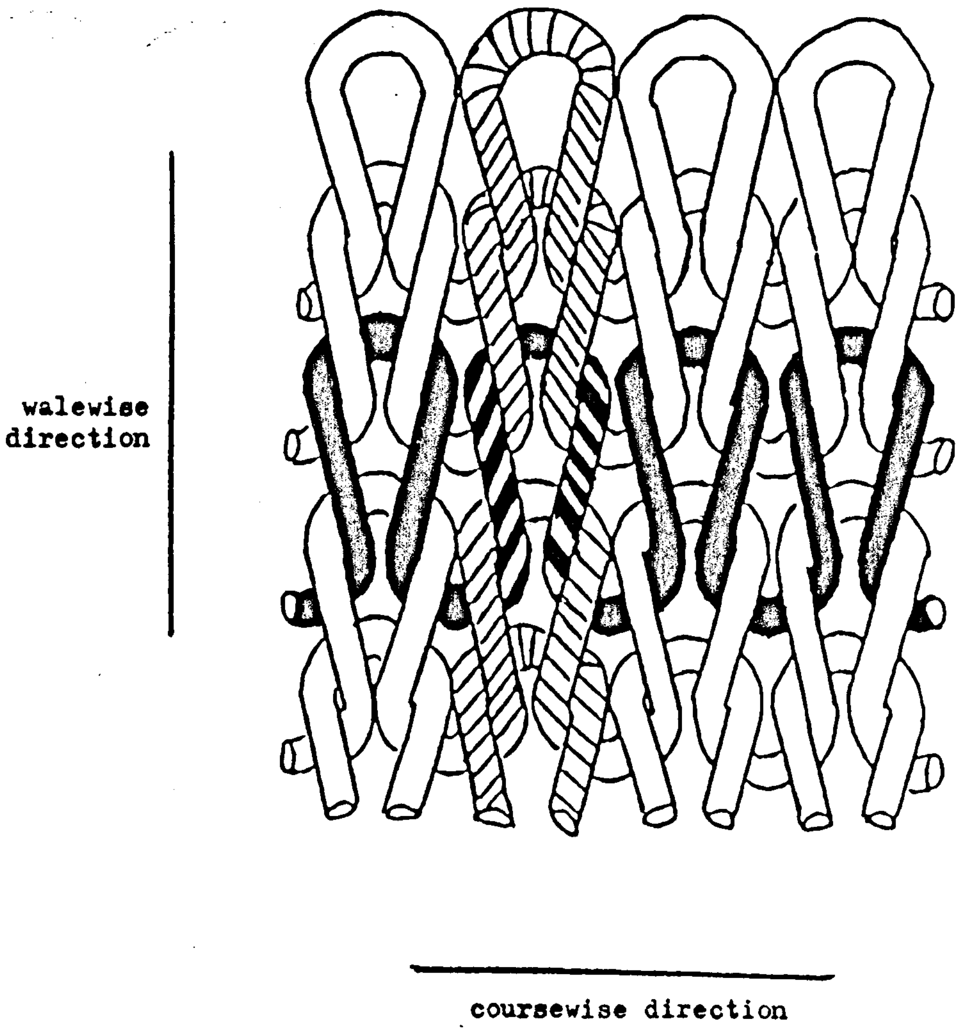
A continuous, vertical crack. The structure remains in tact but the uniform placement of wales is disturbed.

DEFECT : RIP NEEDLE

A continuous, vertical tear. The structure is ruptured with a series of holes of variable sizes being formed. Broken ends of yarn are evident at the edges of the holes.

FIGURE 10

ILLUSTRATION OF WALEWISE/COURSEWISE DIRECTION



DEFECT : TUCK NEEDLE

An intermittent, vertical line. Tiny pin holes are formed at the point where stitch distortions occur.

TYPE : HORIZONTAL

The fault occurs in a coursewise direction (figure 10) where a course forms a row of consecutive loops across the width of the fabric. The fault is continuous in that it extends across a minimum of one centimetre of fabric or more. The defect takes the form of a line or band, the depth of which is determined by the number of consecutive courses affected.

DEFECT : BARRE

The fault appears as fine, widthwise cracks, a condition generally characterised by a somewhat patterned unevenness of appearance. These horizontal lines are continuous and form across the width of the fabric at regular intervals, coinciding with knitted courses.

DEFECT : SLUB $\geq$ 1 CM.

These defects are short, abnormally thick, heavy places in the yarn which manifest themselves in a similar way in the knitted fabric. Slubs are usually symmetrical and occur randomly.

DEFECT : THICK/THIN

Thick and thin fabric is characterised by areas of varying fabric density, giving an overall patchy appearance. Only very severe cases of this defect are detectable at the post knitting stage. Evidence of this defect is more prominent after dyeing.

TYPE : REGIONAL

A structural breakdown occurs causing a hole. The hole manifests itself as a complete circular shape which cuts the background into two parts.

DEFECT : PRESS-OFF

An area of the structure is ruptured creating a hole. The holes vary in size and are remotely circular in shape.

DEFECT : PRESS-OFF ONE BED

An area of the structure where the fabric fails to knit on one bed. The defect appears ovular in shape with a thin web of fabric characterising the defect.

DEFECT : DROPSTITCHES

Individual stitches fail to form and a hole approximating to the size of 1-2 stitches occurs. Dropstitches may be isolated or may occur frequently in large quantities.

DEFECT : SLUB HOLE

An area of the structure is ruptured, creating a hole. Holes vary in size and are remotely circular in shape. Associated with the hole is a short, thick horizontal bar.

DEFECT : KNOT HOLE

An area of the structure is ruptured, creating a hole. Holes vary in size and are remotely circular in shape. A knot is associated with the hole and takes the form of a lump with tail ends of variable lengths. The tail ends may be knitted into the course, appearing as a thickness, or may lie randomly on the surface of the fabric.

TYPE : DISPERSED

Faults form on the surface of the fabric or are knitted into the structure. The faults occur randomly and manifest themselves as tiny specs or lumps of varying sizes.

DEFECT : FIBRE CONTAMINATION

Small balls of fibre accumulated around the yarn. As the yarn is knitted a lump forms in the fabric which is not generally symmetrical. Often the lump will contain foreign fibres, the defect then appears different in colour to the background. These defects occur randomly in the fabric and occasionally have the appearance of thin, horizontal traces of colour.

DEFECT : NEPS

An excessive amount of tangled fibres appear on the face of the fabric. The term excessive is quantifiable by the standard of acceptability set by the manufacturer. Incorporated under this heading are motes (immature, cotton seeds) which appear as tiny black/brown specs on the fabric surface.

DEFECT : KNOTS

A place where two ends of yarn are tied together and form a lump in the fabric which distorts the surrounding background. The tail, of variable length, may be knitted into the course or lie randomly on the surface of the fabric.

5.4.1.2 SURVEY OF DEFECT TERMINOLOGY

The terminology used to describe defects is vast. To capture the range of commonly-used terms requires a survey. A knowledge of this terminology and its usage makes possible the grouping of like or similar terms thus reducing misinterpretation. To statistically quantify frequency of usage of each term permits the reliability of successful recognition to be measured. This approach is particularly useful in the consideration of automated fabric inspection and has potential for existing inspection methods where human inspectors are involved. It is known that inconsistencies occur between examiners and that judgments vary. A knowledge of the statistics of the features may be used to introduce improvements into the standardisation of inspection information. The following applications are suggested:

1. to train human examiners to use a set of vocabulary which consists of the most frequently-used terms.
2. in assigning features of known significance to a defect, human examiners are led to

inspect a fault in a systemmatic and standardised manner.

3. for automated inspection, successful recognition depends partly on identification of combinations of features. Therefore the choice of features and the terminology used to define the features are critical to the recognition process. Knowledge of the significance of each feature provides information against which the success rate of recognition may be measured. Furthermore, the significance of the features determines the order of identification for the recognition process to be most effective. Clearly, where a feature is common to more than one defect, the significance plays a major role at the recognition stage.

THE SURVEY

The object of the survey was to determine the range of terms used to describe the knitting defects common to single jersey and 1 x 1 rib cotton structures. The survey involved 20 subjects in total; 10 were experienced examiners currently employed in the knitwear industry and the remaining 10 were non-examiners whose experience covered a wide range of activities other than textiles. The subjects were men and women, aged from 16 to 60. Each subject was independently required to visually assess a range of defective samples and to select words to describe the defects. Where no defect was apparent to a subject the result is recorded as 'no defect'.

RESULTS OF SURVEY

The results are expressed in tabular form (tables 14-17). For each defect the features are listed in order of significance and the percentage frequency of usage stated in brackets.

TABLE 14

SIGNIFICANCE OF TERMS USED TO DESCRIBE VERTICAL DEFECTS

NEEDLELINE		DROPSTITCH RUN		TUCK NEEDLE	
ladder	(24.4)	ladder	(44.4)	line	(38.2)
line	(19.5)	hole	(11.2)	holes	(19.1)
right down material	(14.7)	longditudinal	(5.5)	unintentional pattern	(19.1)
thin	(7.3)	run	(5.5)	dropped stitches	(9.5)
needle missing	(4.9)	long	(5.5)	small	(4.7)
not straight	(4.9)	horizontal strands	(5.5)	long	(4.7)
long	(4.9)	wide gap	(2.8)	gathers	(4.7)
vertical	(4.9)	1.5" long	(2.8)		
ridge	(2.4)	1.25" long	(2.8)		
within same grain	(2.4)	0.25" wide	(2.8)		
1 mm.wide	(2.4)	line	(2.8)		
narrow	(2.4)	narrow	(2.8)		
big	(2.4)	short	(2.8)		
dark	(2.4)	big	(2.8)		

TABLE 15

SIGNIFICANCE OF TERMS USED TO DESCRIBE HORIZONTAL DEFECTS

BARRE		SLUB >= 1 CM.		THICK/THIN	
lines across	(39.0)	thick yarn	(20.8)	no defect	(33.3)
horizontal	(12.3)	heavy stitching	(16.7)	line	(22.3)
ladders across	(12.3)	line across	(16.7)	dark line	(11.1)
regular spaced	(7.3)	horizontal	(12.5)	light line	(5.5)
stripes	(4.9)	dark	(12.5)	uneven	(5.5)
thick stitching	(4.9)	mark	(8.2)	horizontal	(5.5)
rows of missed stitching	(4.9)	stripe	(4.2)	bands	(5.5)
bands	(2.4)	1" long	(4.2)	tight course	(5.5)
runs	(2.4)	long	(4.2)	slightly less dense	(5.5)
patterned	(2.4)				
loose stitches	(2.4)				
thin	(2.4)				
holes	(2.4)				

TABLE 16

SIGNIFICANCE OF TERMS USED TO DESCRIBE REGIONAL DEFECTS

PRESS-OFF		PRESS-OFF 1 BED		DROPSTITCHES		SLUB HOLE	
hole	(48.8)	small ladders	(31.3)	hole	(73.2)	hole	(37.0)
big	(29.4)	horizontal	(9.4)	small	(15.4)	thickening	(14.8)
broken ends of yarn	(4.9)	loops visible	(6.3)	one stitch missing	(3.8)	horizontal	(11.2)
snagged	(4.9)	2.5" long	(6.3)	cut	(3.8)	line	(7.4)
circular	(2.4)	thin	(6.3)	broken stitch	(3.8)	variation in density	(7.4)
regular	(2.4)	abraded	(6.3)			ridge	(7.4)
2 cm. diameter	(2.4)	dropped stitches	(3.1)			big	(3.7)
0.5" diameter	(2.4)	7 cms. long	(3.1)			circular	(3.7)
see through	(2.4)	large	(3.1)			0.5 cm. diameter	(3.7)
		bulk of fabric missing	(3.1)				
		caught	(3.1)				
		torn	(3.1)				
		not knitting 1 bed	(3.1)				
		tiny holes	(3.1)				
		dark	(3.1)				
		rough	(3.1)				
		spiders web	(3.1)				

TABLE 17

SIGNIFICANCE OF TERMS USED TO DESCRIBE DISPERSED DEFECTS

KNOTS		NEPS		FIBRE CONTAMINATION (LUMP)		FIBRE CONTAMINATION (LINE)	
pulled	(57.1)	no defect	(90.0)	pink	(24.0)	small	(20.0)
loose end	(14.3)	black marks	(10.0)	different colour	(12.0)	black	(12.0)
thread broken	(14.3)			small	(8.0)	dark	(12.0)
catches	(14.3)			fluff	(8.0)	line	(8.0)
				uneven texture	(8.0)	different colour	(8.0)
				blobs	(8.0)	0.5 cm. long	(8.0)
				thick	(8.0)	oily cotton	(4.0)
				trapped fibre	(8.0)	thread missing	(4.0)
				horizontal	(4.0)	horizontal	(4.0)
				specs	(4.0)	2 mm. long	(4.0)
				marks	(4.0)	mark	(4.0)
				dots	(4.0)	short	(4.0)
						grey	(4.0)
						foreign fibre	(4.0)

DISCUSSION OF RESULTS

As a result of the survey a wide range of defect terms has been amassed. Clearly, some defects are more easily detectable than others. In the case of a knot hole, none of the subjects detected the knot at the edge of the hole. Six subjects failed to detect the thick/thin defect and only two subjects detected neps, both describing them as black marks. It is noteworthy that the 10 subjects employed as inspectors did not display a specialised or uniform set of vocabulary. To minimise inconsistencies between human inspectors, this evidence supports the need for a standardised set of defect terms or a common defect inspection language to be incorporated in training schemes. The purpose of the survey was to freely extract descriptions of defects and not to check the subjects' ability to correctly identify the defects. By this method, the acquisition of human knowledge can be incorporated into an intelligent knowledge-base as part of an automated inspection system. For an automated system to recognise defects, sets of salient defect features must be established. This information must then be presented to the computer in an intelligible form.

GROUPING OF LIKE TERMS

As shown in tables 14-17, certain similar terms can be grouped into synonym lists. In the development of an automated inspection system, defect feature terminology is very limited to avoid miss-classification of defects. Where the image processing system is driven by the 'expert' knowledge-base with a semantic processor to interface the two, optimum performance is achieved when the processor has a restricted number of terms to interpret. The use of synonym lists allows a wider range of terms for human input. The application of this approach is described in chapter 7. Table 18 contains synonym lists from the results of the survey.

TABLE 18

SYNONYM LISTS FROM SURVEY RESULTS

hole, holes, gap, see through

circle, circular, round

horizontal, lines across, line across, rows , course, courses, ladders across

line, lines, band, bands, run, runs, stripe, stripes, thickening, ridge

big, large, wide

abraded, rough, uneven

caught, torn, ripped, broken, cut

narrow, thin

vertical, longditudinal

ladder, horizontal strands

periodic, patterned, regular, regular spaced, even

dots, specs, marks, blobs

dispersed, scattered

From the results, two types of features are used to describe the defects. The most commonly used are the visual features which have been discussed in great detail. The second type are the numerical quantifiers. In knitted fabrics a particular defect rarely recurs with exactly the same appearance. The survey provides an indication of the parameters available to further distinguish the features. The application of numerical parameters is discussed in chapter 7. Table 19 contains a list of defect parameters.

TABLE 19

LIST OF NUMERICAL PARAMETERS

length
width
area
diameter
number per area
colour
straight/curved

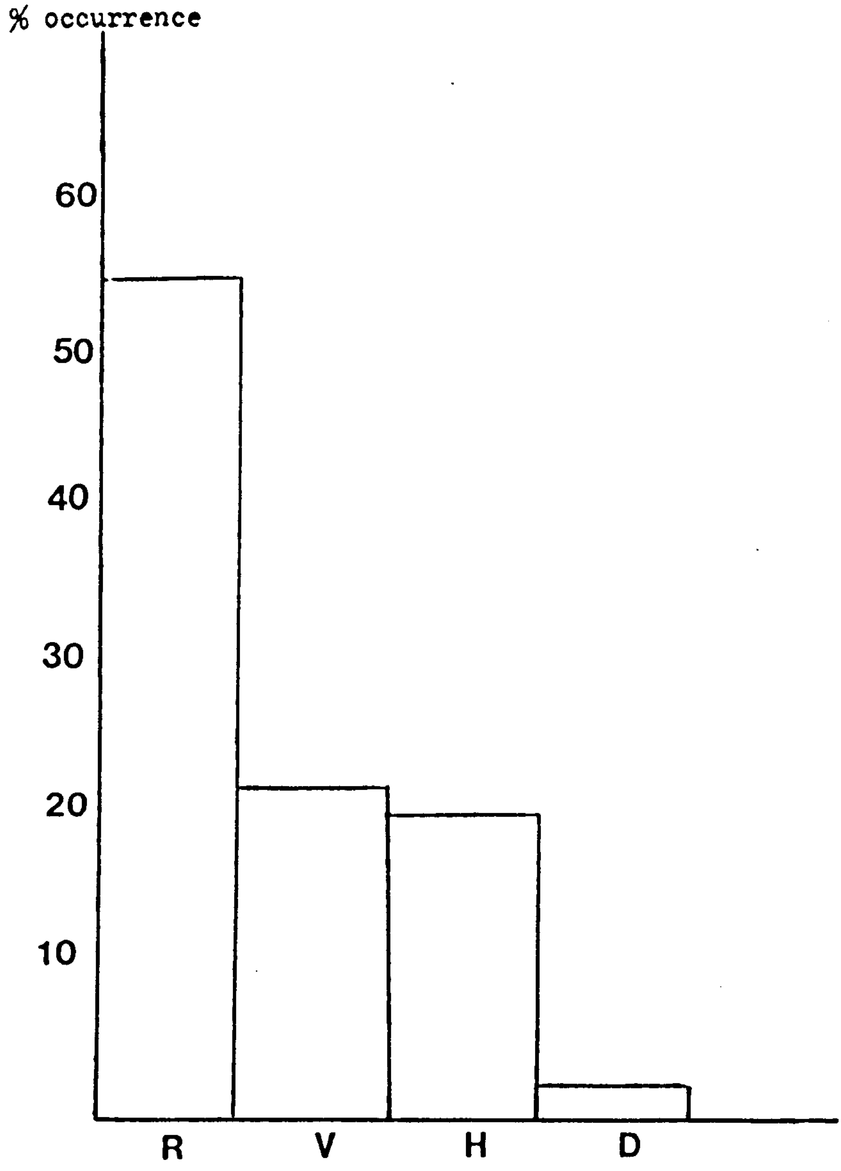
5.4.1.3 FEATURE TREE DEFECT CLASSIFICATION

Central to the feature tree classification approach is the ranking of defects, features and types. The relevance of this approach is to facilitate systenmatic searching of the tree by a computer, a process which otherwise would have occurred in an adhoc manner. Figures 11 and 12 show the frequency of occurrence of defect types for 1 x 1 rib and single jersey fabrics respectively.

FIGURE 11

FREQUENCY OF OCCURRENCE OF DEFECT TYPES

1x1 RIB



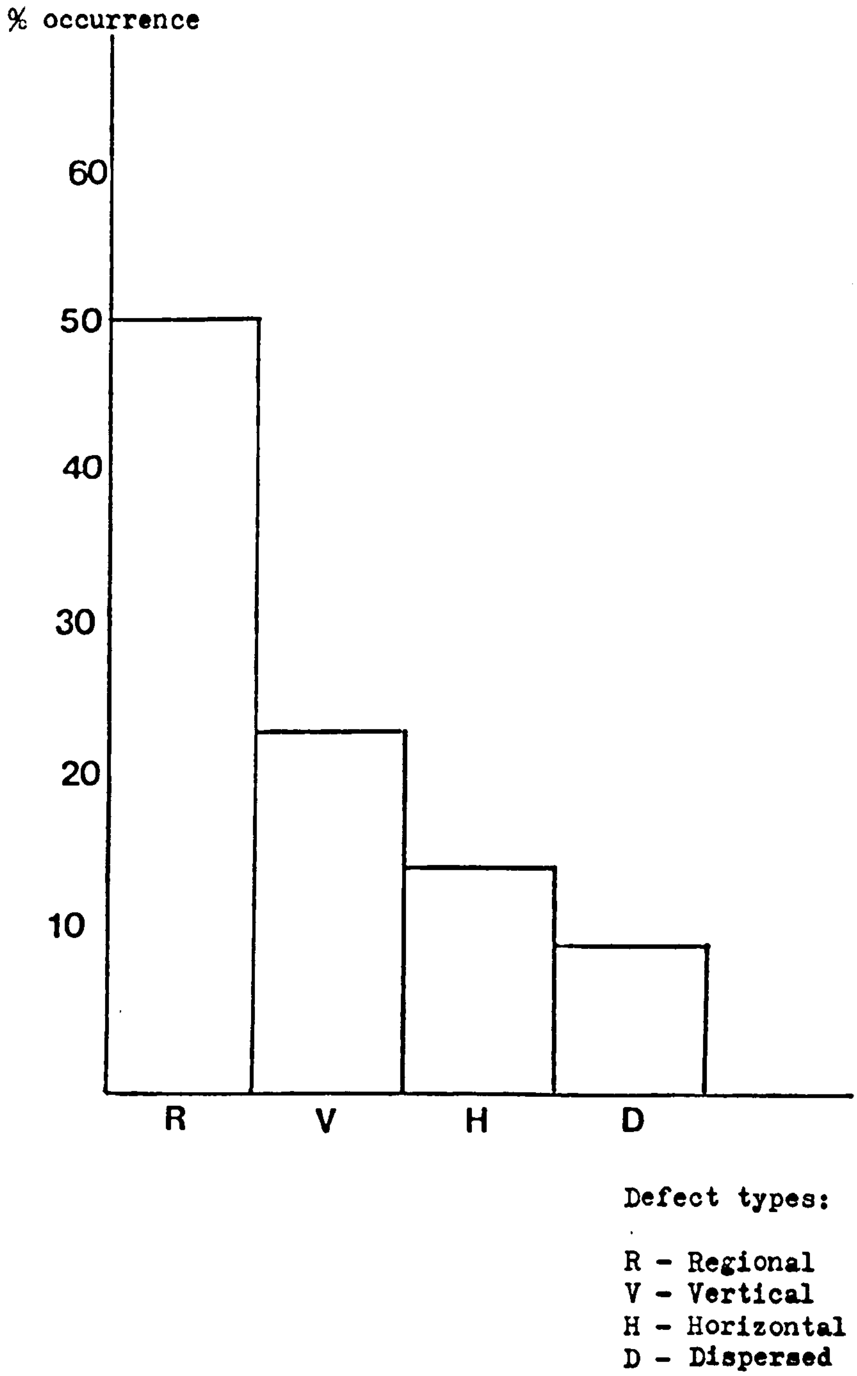
Defect types:

R - Regional
V - Vertical
H - Horizontal
D - Dispersed

FIGURE 12

FREQUENCY OF OCCURRENCE OF DEFECT TYPE

SINGLE JERSEY



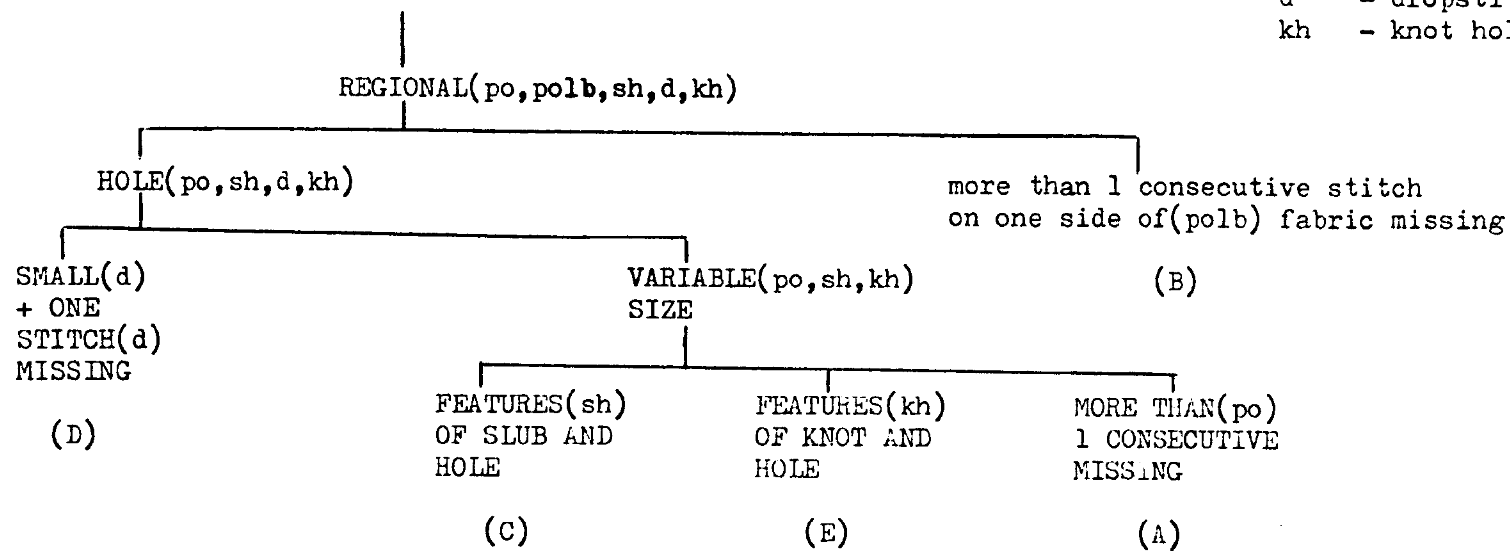
In the ensuing classifications, the defect types are ranked in order commencing with the most frequently occurring type (regional) in part 1. The ranking of individual defects is represented by alphabetical notation.

1 X 1 RIB FEATURE TREE CLASSIFICATION

PART 1

KEY ()

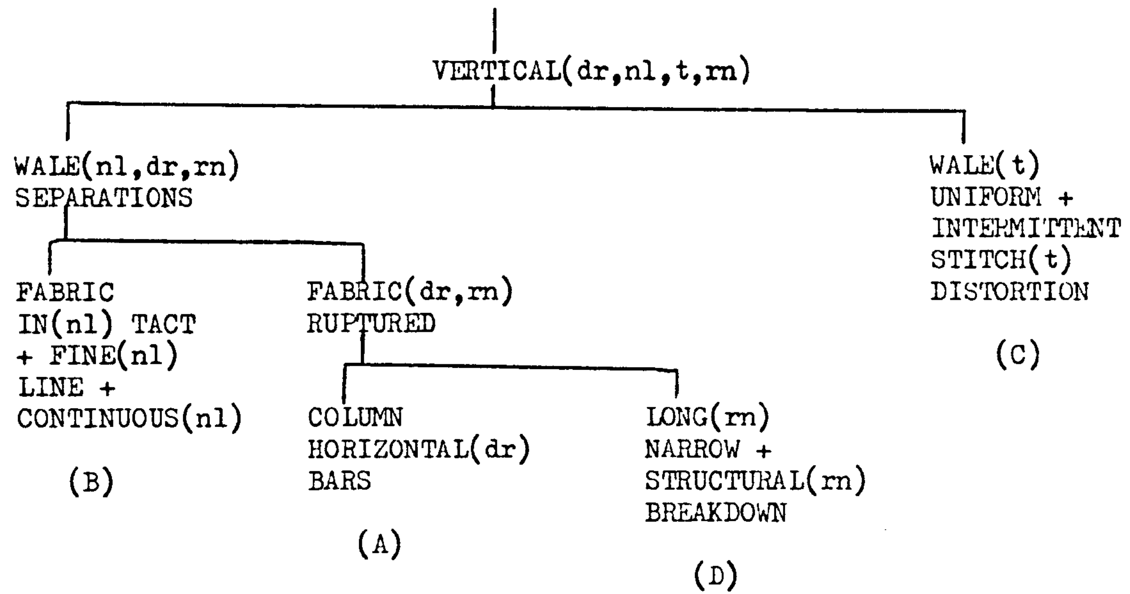
po - press off
polb - press off 1 bed
sh - slub hole
d - dropstitch
kh - knot hole



1 X 1 RIB FEATURE TREE CLASSIFICATION

PART 2

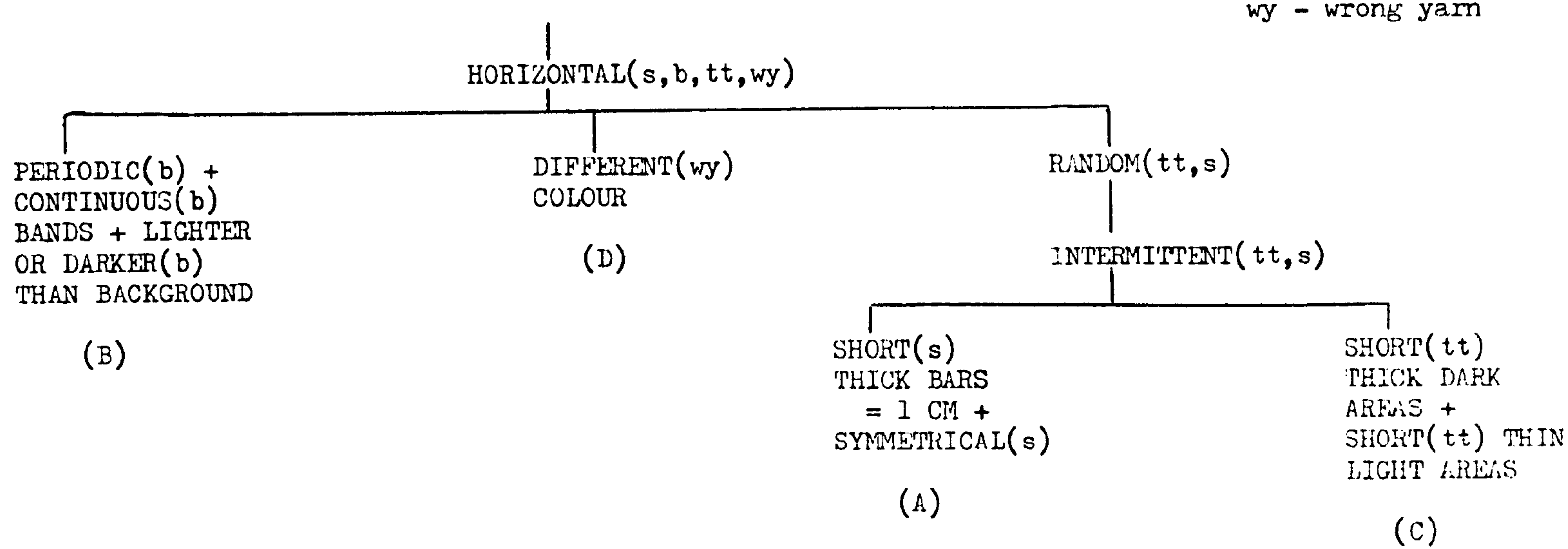
KEY ()
dr - dropstitch run
nl - needleline
t - tucking needle
rn - rip needle



1 X 1 RIB FEATURE TREE CLASSIFICATION

PART 3

KEY ()
s - slub
b - barre
tt - thick/thin
wy - wrong yarn

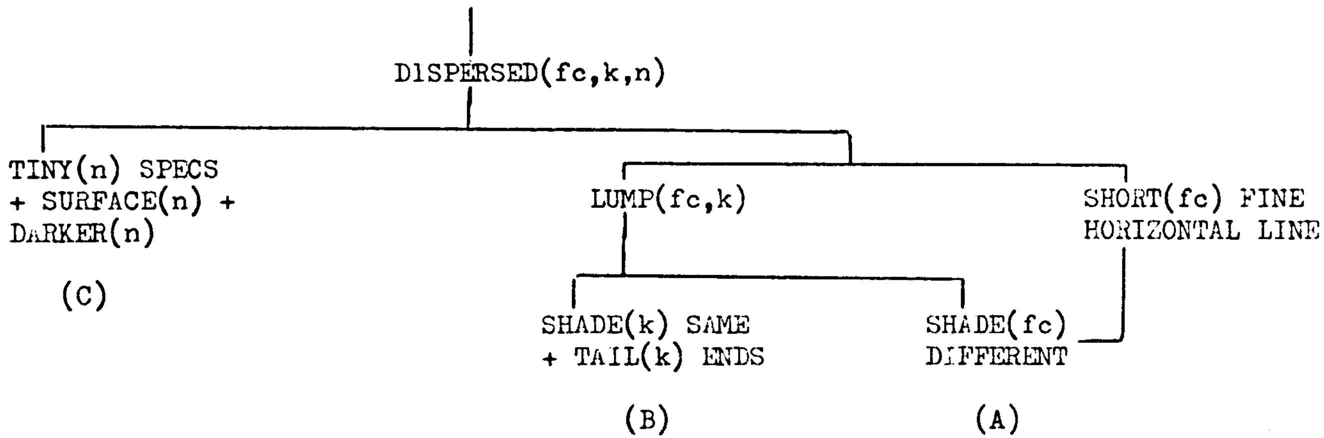


1 X 1 RIB FEATURE TREE CLASSIFICATION

PART 4

KEY ()

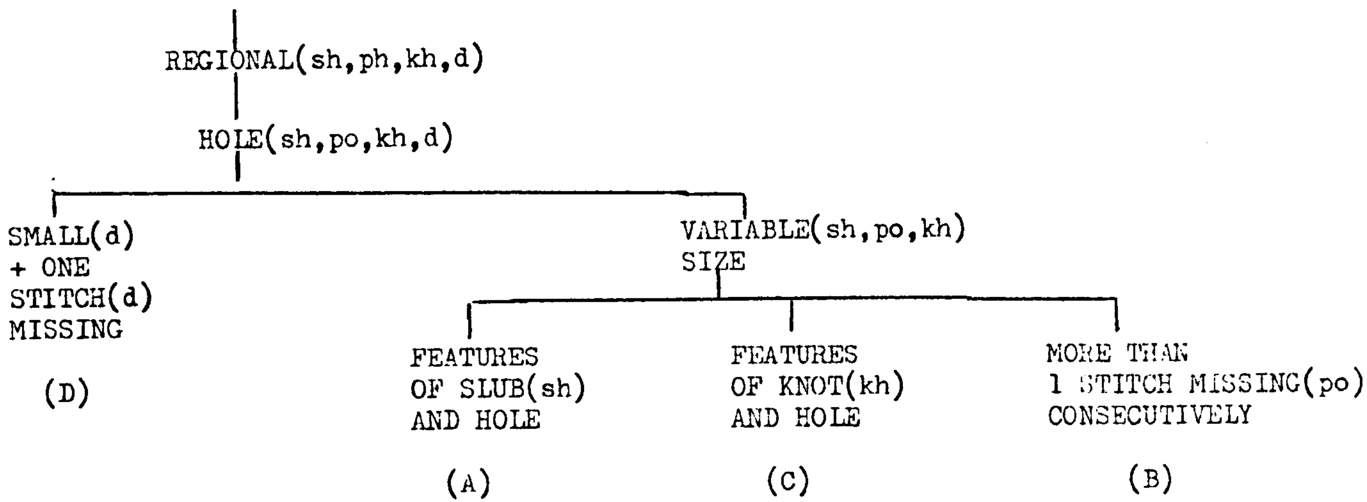
fc - fibre contamination
k - knots
n - neps



SINGLE JERSEY FEATURE TREE CLASSIFICATION

PART 1

KEY ()
sh - slub hole
po - press off
kh - knot hole
d - dropstitch



SINGLE JERSEY FEATURE TREE CLASSIFICATION

PART 2

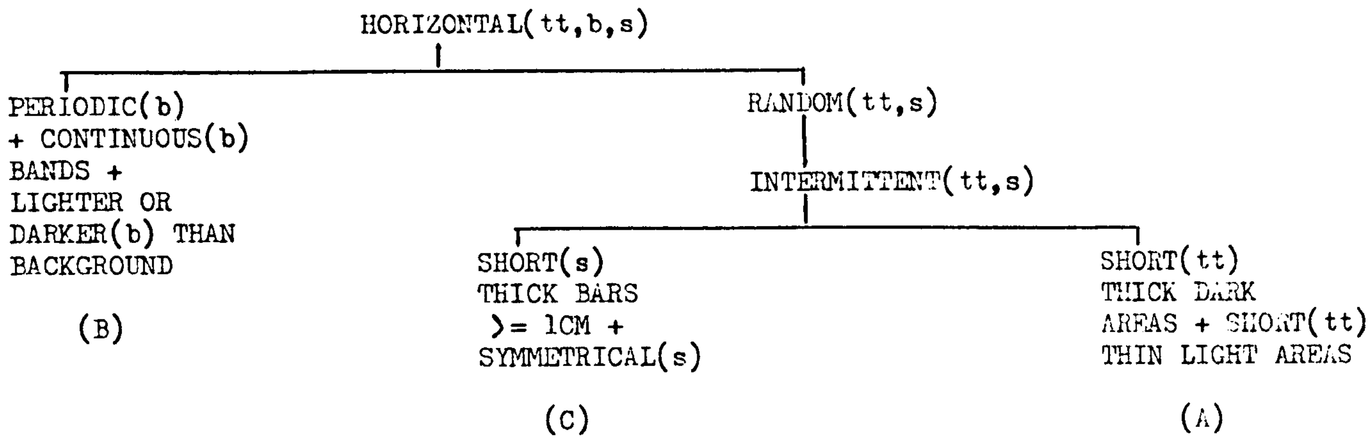
KEY ()
- dr - dropstitch run
- nl - needleline
- t - tuck needle
- rn - rip needle

- VERTICAL(dr,nl,t,rn)
  - WALE(nl,dr,rn) SEPARATIONS
    - FABRIC IN(nl) TACT + FINE(nl) LINE + CONTINUOUS(nl) (A)
    - FABRIC(dr,rn) RUPTURED
      - COLUMN(dr) HORIZONTAL BARS (B)
      - LONG(rn) NARROW + STRUCTURAL(rn) BREAKDOWN (D)
  - WALE(t) UNIFORM + INTERMITTENT STITCH(t) DISTORTION (C)

SINGLE JERSEY FEATURE TREE CLASSIFICATION

PART 3

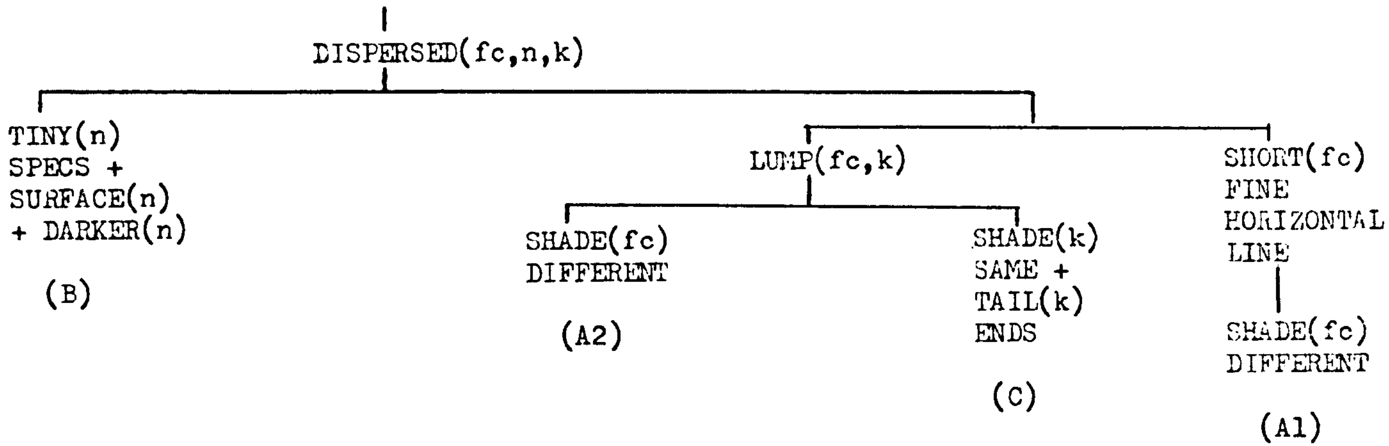
KEY ()
tt - thick/thin
b - barre
s - slub



SINGLE JERSEY FEATURE TREE CLASSIFICATION

PART 4

KEY()
fc - fibre contamination
n - neps
k - knots



5.4.2 NUMERICAL DESCRIPTION APPROACH

The use of visual features is the first of three approaches towards the classification of knitting defects. In considering the development of a classification scheme for automated inspection, the computer must be able to interpret the terms provided. For this reason a numerical description classification has been included which describes the features in terms of a ratio of vertical to horizontal. This approach cannot replace the feature tree approach because certain features are not definable by this method, the numerical descriptions provided serve to enhance the visual features for computer intelligibility.

The scale used in the classification ranges from 1 to infinity where 1 represents the minimum distance of 1 course or 1 wale. Infinity represents the maximum distance. To each defect a numerical description is assigned in the form of a ratio. A set of conditions are also necessary for certain defects, these conditions accommodate the size variations which occur. Adjustment of the condition values allows for the setting of an accept/reject threshold, the level of which may be varied to meet the specific standard required by a manufacturer. The classification incorporates the visual features denoted by the numerical values and includes under 'other features' additional features which may be useful in classifying defects.

5.4.2.1 NUMERICAL DESCRIPTION CLASSIFICATION

SCALE

1 MINIMUM DISTANCE

(vertical = 1 course)
(horizontal = 1 wale)

MAXIMUM DISTANCE

(full width = infinity)
(full length = infinity)

DEFECT	NUMERICAL DESCRIPTION (V:H)	(CONDITION)	VISUAL FEATURES	OTHER FEATURES
BARRE	1:infinity		THIN, FULL-WIDTH HORIZONTAL LINE	RECURS PERIODICALLY
SLUB	1:1+X	$X >= 7$	BAR, VARIABLE LENGTH >1 CM.	RANDOM
THICK/THIN	1:10-X	$0 < X <= 15$	BAR, HORIZONTAL	FAULT LENGTH VARIABLE ACROSS A COURSE, PATCHY, UNWANTED PATTERN
NEEDLELINE	<infinity:1		LONG, THIN, VERTICAL, LINE	RANDOM
RIP NEEDLE	<infinity:1+X	$0 < X <= 5$	LONG, VARIABLE WIDTH, VERTICAL LINE	RAGGED EDGES, FABRIC SPLIT
DROPSTITCH RUN	<infinity:1+X	$0 < X <= 3$	LONG, VARIABLE WIDTH, VERTICAL LINE	LADDERLIKE

DEFECT	NUMERICAL DESCRIPTION (V:H)	(CONDITION)	VISUAL FEATURES	OTHER FEATURES
TUCK NEEDLE	< infinity:1		VARIABLE LENGTH THIN, VERTICAL LINE	INTERMITTENT, STITCH DISTORTION
NEPS	1:1		SMALL SPEC	RANDOM, DARK SPECS >= 5 NEPS/3CMS.SQ.
FIBRE CONTAMINATION	1+X:1+X	X <= 3	VARIABLE SIZE, CIRCULAR	LUMP, DIFFERENT COLOUR TO BACKGROUND, RANDOM
FIBRE CONTAMINATION	1:1+X	X < 10	THIN, HORIZONTAL LINE	DIFFERENT COLOUR TO BACKGROUND, RANDOM
KNOTS	1:1+X + 1+X:1+X	X <= 3 X < 5	SHORT BAR HORIZONTAL, AND ATTACHED TO DEFECT CIRCULAR VARIABLE SIZE	LUMP, RANDOM, >= 3/10CMS.SQ. LUMP ADJOINING SLUB
PRESS-OFF	20-X:20-Y	X <= 18 Y <= 18	ROUGHLY CIRCULAR, VARIABLE SHAPE AND SIZE AREA	HOLE
PRESS-OFF 1 BED	20-X:20-Y	X <= 18 Y <= 18	ROUGHLY CIRCULAR VARIABLE SHAPE AND SIZE AREA	AREA OF FABRIC MISSING ON ONE SIDE ONLY, LEAVING A THIN WEB OF FABRIC
DROPSTITCHES	1:1		SMALL, CIRCULAR	HOLE, RANDOM, ISOLATED OR MULTIPLE
SLUB HOLE	1:1+X + 10-X:10-X	X >= 3 X < 10	HORIZONTAL BAR VARIABLE LENGTH ATTACHED TO DEFECT CIRCULAR, VARIABLE SIZE	SLUB ADJOINING HOLE
KNOT HOLE	1:1+X + 1+X:1+X + 10-X:10-X	X >= 3 X < 5 X < 10	HORIZONTAL BAR, ATTACHED TO SMALL CIRCULAR DEFECT AND ADJOINING DEFECT CIRCULAR, VARIABLE SIZE	KNOT ADJOINING HOLE

5.4.3 TECHNICAL STRUCTURE ANALYSIS APPROACH

The way in which a classification is developed depends largely on the following two factors:

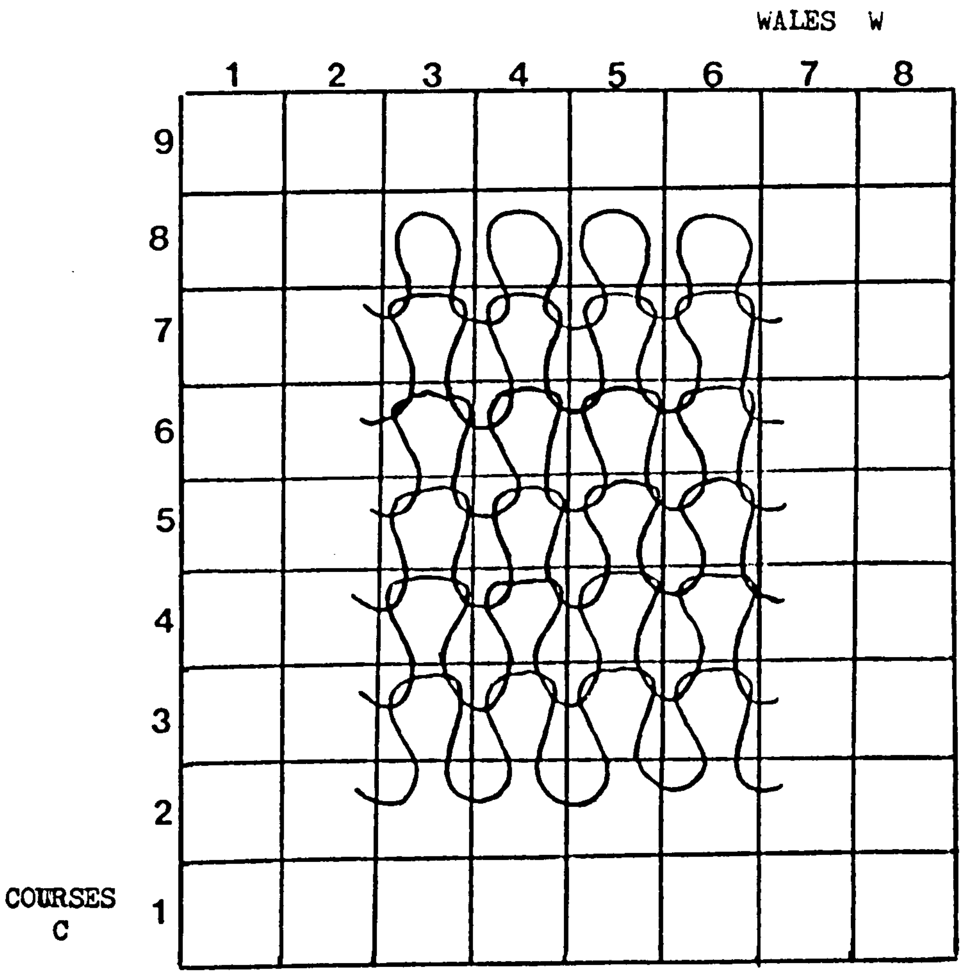
1. the end use of the classification.
2. the nature of the defects to be classified.

In human inspection the inspector has available to him other physical attributes besides vision such as, touch, smell and hearing to assist in the identification of the defects. In automated visual inspection, successful defect identification depends on the defect knowledge acquired and the way in which this information is presented to the system for integration. Taking into consideration the diverse nature of the range of widespread to localised defects in knitted textile materials, it is important to supply a compound descriptive element in the form of a knowledge-base. As illustrated in the first two approaches described, the expression of defect information in different forms enhances the likelihood of successful recognition. As with a numerical classification, this approach aims to provide the computer with parameters against which the defects may be assessed.

Figure 13 shows a fabric construction in grid format where each stitch is represented by a square on the grid. The courses and wales are numbered for ease of defect location.

FIGURE 13

FABRIC CONSTRUCTION IN GRID FORMAT



This form of classification is incomplete as an independent documentation of defects as it fails to provide a comprehensive analysis of all defects. By this method, discernment of defects within a type is impossible, neither is it practical to attempt regional defect analysis as, by their very nature, these defects vary considerably in shape and size. A major advantage of this technique is in the identification of point or localised defects. Cases where the defect is confined to the size of one stitch is a strong indication of dropstitches or less probably tuck stitches. Another asset to this approach is its suitability for the recognition of periodic recurrence of barre.

5.4.3.1 TECHNICAL STRUCTURE ANALYSIS CLASSIFICATION

NO DEFECTS

SCAN ALL C AND NUMBER OF DEFECTS ON C = 0
SCAN ALL W AND NUMBER OF DEFECTS ON W = 0

HORIZONTAL - BARRE

SCAN C AND NUMBER OF DEFECTS ON C > 1
SCAN C+2 AND NUMBER OF DEFECTS ON C = 0
SCAN C-2 AND NUMBER OF DEFECTS ON C = 0
SCAN W AND NUMBER OF DEFECTS ON W = 1
SCAN ALL W AND NUMBER OF DEFECTS ON W = 1
SCAN C+X AND NUMBER OF DEFECTS ON C > 1
SCAN C+(X+2) AND NUMBER OF DEFECTS ON C = 0
SCAN C+(X-2) AND NUMBER OF DEFECTS ON C = 0
SCAN C+2X AND NUMBER OF DEFECTS ON C > 1
SCAN C+(2X+2) AND NUMBER OF DEFECTS ON C = 0
SCAN C+(2X-2) AND NUMBER OF DEFECTS ON C = 0

VERTICAL

SCAN C AND NUMBER OF DEFECTS ON C = 1
SCAN C-1 AND NUMBER OF DEFECTS ON C = 0
SCAN C+(1 to X) AND NUMBER OF DEFECTS ON C = 1
SCAN C+(X+1) AND NUMBER OF DEFECTS ON C = 0
SCAN W AND NUMBER OF DEFECTS ON W > 1
SCAN W-1 AND NUMBER OF DEFECTS ON W = 0
SCAN W+1 AND NUMBER OF DEFECTS ON W = 0

DISPERSED - LOCALISED OR POINT DEFECT

SCAN C AND NUMBER OF DEFECTS ON C = 1
SCAN C-1 AND NUMBER OF DEFECTS ON C = 0
SCAN C+1 AND NUMBER OF DEFECTS ON C = 0
SCAN W AND NUMBER OF DEFECTS ON W = 1
SCAN W-1 AND NUMBER OF DEFECTS ON W = 0
SCAN W+2 AND NUMBER OF DEFECTS ON W = 0

5.5 SUMMARY

To capture the specialist knowledge of a human inspector, two industrial surveys have been conducted. From these surveys the following information has been obtained:

1. the knitting defects in 1 x 1 rib and single jersey cotton fabrics.
2. the frequency of occurrence of the knitting defects.
3. a range of visual defect features.
4. the frequency of usage of visual features in defect identification.

For optimum effectiveness of automated inspection using an intelligent knowledge-base approach, the presentation of defect information has been structured in consideration of the following factors:

1. computer intelligibility.
2. rapid information access capability.
3. structural flexibility.

Three approaches to the classification of knitting defects are described and their relative merits for automated inspection discussed.

CHAPTER 6

INTERACTIVE CAPABILITIES OF AN AUTOMATED FABRIC INSPECTION SYSTEM

Unless one is a genius, it is best to aim at being intelligible.

Anthony Hope

6.0 Powerful knowledge-based computer systems are rendered useless if users cannot easily and efficiently communicate with them. There are two major areas for consideration:

1. cognitive compatibility.
2. feedback/feedforward capability.

If an intelligent knowledge-based system is to be responsible for complex problem solving, decision-making and giving advice, then it is vital that it is designed in such a way that there is a high degree of cognitive compatibility between the user and the system. Although the system need not be a psychological model, exactly imitating a human's reasoning process, it must employ similar knowledge structures.

The 'knowledge acquisition' aspect of building an intelligent knowledge-base has been considered in chapter 5. Chapter 6 discusses the importance of the interactive capability of an automated inspection system in the context of defect causes and automatically recommending remedial actions at source.

6.1 INTRODUCTION

Until recently, manufacturing industry has been able to assume that if something goes wrong, there will be someone around to detect it and then ensure the fault is corrected. The advent of automation renders this attitude unacceptable. To compensate for the communication skills of the human inspector, a knowledge-based system must incorporate interactive capabilities.

In the context of fabric inspection, where the inspector is not necessarily a knitting expert, it is advantageous to include in the knowledge-base information about the causes of defects with recommendations for correction at source. Clearly, the absence of a human inspector necessitates automatic information feedback.

As recently as 1982, Sweranowsky incorporated in his classification scheme the possible causes of defects, the areas of responsibility and recommendations for remedial actions. The term 'remedial' implies repair of the fault to restore the goods to a perfect condition. In single jersey and 1 x 1 rib cotton fabrics restoration of the fabric to a perfect state is rarely practical for the following reasons:

1. the cost of repair work in operative time and effort usually far outweighs the value of the fabric in the end use item.
2. the structures are relatively simple and open. Once a rupture or distortion disturbs the uniformity of the fabric, it is an extremely difficult and specialised task to restore the structure and achieve a flawless appearance.

6.2 DEFECT CAUSES AND REMEDIAL ACTIONS AT SOURCE

A study of possible causes of defects has been conducted. The causes may be categorised into three main areas. Table 20 shows that whilst some defects may be attributed solely to one cause, others such as barre may be due to mechanical failure or to a quality problem with the raw materials. In indicating the general area in which a fault has occurred at source, it is desirable to offer specific recommendations to rectify the source of the problem. This action does not prevent the occurrence of the defect, in the first instance, but the quantity of waste fabric produced is minimised. This approach is effective only when fabric inspection immediately proceeds the knitting operation. Table 21 is an expansion of table 20 and incorporates lists of recommended actions at source. No order of priority is assigned to the lists.

6.3 SUMMARY

Towards the fulfillment of the requirements of an automated fabric inspection system, a study has been conducted of defect causes and remedial actions at source. This information along with the defect classifications of the previous chapter will be incorporated into a knowledge-base towards the development of an intelligent knowledge-base inspection system.

TABLE 20

CAUSES OF DEFECTS

MECHANICAL		RAW MATERIALS		OPERATOR
knitting m/c		yarn		knitter
needleline	barre	thick/thin	knot hole	
dropstitch run	press off	slub	knots	
tuck needle		slub hole	fibre contamination	
rip needle		neps		
dropstitches				
press off 1 bed				

TABLE 21

RECOMMENDATIONS FOR REMEDIAL ACTION AT SOURCE

DEFECT	CAUSE	ACTION
barre	knitting m/c	check positive feed
"	"	no positive feed-check for improper cam adjustment
"	"	check yarn tensions
"	"	check cleanliness of m/c
"	"	check m/c for dial/cylinder relationship
"	"	check m/c for faulty take-down mechanism
"	yarn	measure singles/folding/snarling twist
"	"	check yarn count
thick/thin	yarn	check for count variation in yarn package
"	"	check for twist variation in yarn package
slub	yarn	check evenness of yarn
"	"	refer to spinner-clearing/winding faulty
needleline	knitting m/c	check m/c for defective needle
"	"	check m/c for damaged sinker
"	"	check m/c for worn or unevenly spaced trick walls
"	"	check m/c for dirty tricks
"	"	check lubrication of knitting elements
dropstitch run	knitting m/c	check m/c for broken needle or jack
" "	"	check needle for bent or stiff latch

DEFECT	CAUSE	ACTION
tuck needle	knitting m/c	check m/c for malfunctioning needle or jack
" "	"	check if take-down mechanism too loose
" "	"	check for improper stitch cam setting
" "	"	check if needles move too freely in the tricks
" "	"	check if the dial height set too low
" "	"	check for dirt in trick walls
rip needle	knitting m/c	check m/c for damaged needle
dropstitches	knitting m/c	check m/c for improperly set yarn carriers
"	"	check if yarn is in the wrong hole of carrier
"	"	check m/c for needle damage
"	"	check if take-down mechanism is too loose
"	"	check fabric quality - if too tight/slack adjust stitch settings accordingly
"	"	check if dial height too high
"	"	check m/c for positive feed slippage
"	"	check if needle timing set wrong
"	"	check if needle tricks clogged
"	"	check if dial latch closing under yarn carrier
"	"	check if dial latch closing near heel of carrier
slub hole	yarn	refer to spinner-clearing/winding faulty
press off	knitting m/c	check fabric quality - if too tight/slack, adjust stitch cam accordingly
" "	"	check if take-down mechanism too tight
" "	"	check positive feed system
" "	"	check for dirty/clogged surfaces through/over which yarn passes
" "	"	check for defective needles cutting the yarn

DEFECT	CAUSE	ACTION
press off	yarn	check for badly wound package
" "	"	check strength of yarn
" "	"	check for improper threading up of m/c
knot hole	yarn	refer to spinner-clearing/winding faulty
" "	knitter	refer to knitter-badly tied knots
knots	yarn	refer to spinner-clearing/winding faulty
"	knitter	refer to knitter-badly tied knots
fibre contamination	yarn	refer to spinner-ginning process faulty
" "	knitter	refer to knitter-cross-contamination fibre during blowing down of m/c
neps	yarn	refer to spinner-ginning process faulty

CHAPTER 7

DEVELOPMENT OF INTELLIGENT KNOWLEDGE-BASE SYSTEM FOR DEFECT RECOGNITION AND CLASSIFICATION

I must create a system or be enslaved by another man's....

W. Blake

7.0 Knowledge-base systems constitute the best means currently available for codifying the problem-solving know-how of human experts. Experts tend to express most of their problem-solving techniques in terms of a set of situation - action rules. This suggests that a similar method of building a knowledge intensive expert system is required. Emphasis is placed on the computer hardware employed for the research and shows the development of an automated fabric inspection system which comprises three integral parts. This chapter concentrates mainly on one of these parts - the development of the defects database.

7.1 INTRODUCTION

Two key properties characterising the suitability of a knowledge-base system for automated fabric inspection are as follows:

1. integration with a conventional software system.
2. shareability of knowledge-bases among several related applications.

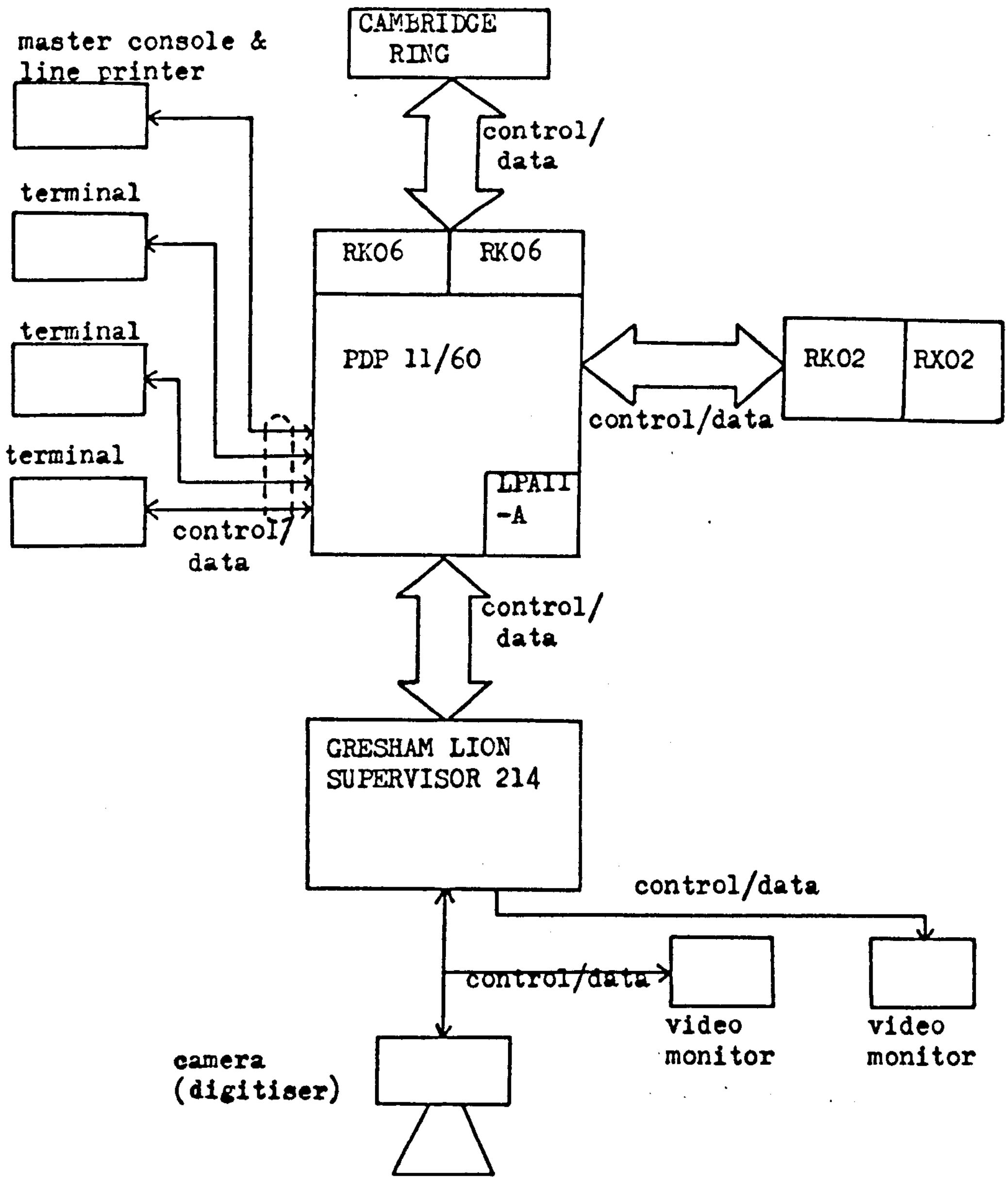
Modern hardware and software are becoming more complex, an important feature in the development of an intelligent knowledge-base system is its compatibility to the computer environment within which it must operate.

7.2 PROTOTYPE IMAGE PROCESSING COMPUTER SYSTEM

The main research tool employed for the development of an automated fabric inspection system is shown in figure 14. This consists of a PDP11/60 host minicomputer with 256 Kbytes of main memory, two RK06 Disk Drives providing a total of 28 Mbytes of storage and two RX02 8 inch Floppy Disk Drives providing a further 1 Mbyte of memory. The PDP11/60 interfaces with a Gresham Lion Supervisor 214 Computer Graphics and Image Display System enabling a 1024 x 512 pixel image (maximum), with 256 grey levels, to be stored. Image data is input from a Closed Circuit Television Camera and can be displayed on a high resolution video monitor. The camera can be manoeuvered and focussed on a specific area of the fabric, if required. The fabric is viewed in a static position under transmitted or reflected light conditions. The analog signal from the camera is converted into binary digits. These signals can be used to build a complete image on a frame in the computer's backing store. The advantage of the frame store is that the Central Processing Unit of the computer may draw information from the image stored on the frame for its calculations. The essential information can then be transferred to the RAM working store. Statistical procedures are used to refine and enhance the captured image and to produce mathematical assessments and judgements of important features. On completion of these assessment routines,

FIGURE 14

IMAGE PROCESSING COMPUTER SYSTEM



output signals from the Central Processing Unit of the computer may be used to produce a visual display, a computer print-out or a go/no-go control facility in an industrial setting.

7.3 THE DEVELOPMENT OF AN AUTOMATED FABRIC INSPECTION SYSTEM

The development of a system comprises three integral parts (figure 15).

FIGURE 15

INTEGRAL PARTS OF INTELLIGENT KNOWLEDGE BASE SYSTEM
(IKB SYSTEM)

DEFECT DETECTION ALGORITHMS	- - -	SEMANTIC PROCESSOR	- - -	DATABASE OF DEFECT FEATURES

The defect detection algorithms developed are described by Hashim et al (1984) and more recently by Clark et al (1986) and form part of a parallel line of research towards the automation of fabric inspection. The semantic processor software is the interface between (a) the image processing algorithms for defect detection and feature extraction which are low level numerical operations and (b) the database of defect features which recognises and classifies the defect and is produced by an expert system.

7.4 DEVELOPMENT OF THE DEFECTS DATABASE

Development of the defects database has taken three forms.

The technique for representing knowledge as data structures and processes on these data structures is provided by Prolog. Prolog is a high level, artificial language that stores knowledge in the form of relations, Horn clauses and the process of inference.

7.4.1 FEATURE TREE APPROACH

The classification is represented in the form of a tree structure, with defect types forming the roots and the defect features the branches. Each branch sub divides into further branches which form structures within structures. The defects are presented at the tips of the branches. Defect identification occurs by the systematic searching of the tree, the path of which is determined by user response.

Where the user is uncertain of the response an 'unknown' option is incorporated. The user is then directed to another feature within the tree structure in order to clarify the uncertainty and to reduce the possibility of mis-classification. By this method only the relevant branches of the tree are considered in order to minimise search time. Figures 16 –16d illustrate the structure of the feature tree defect classification database, the program for which is detailed in Appendix C.

This program is modelled on the feature tree classification shown in section 5.4.1.3, using a human being as the user of the database. For automated inspection, this approach

FIGURE 16

KEY TO FIGURES 16a-16d

PO - PRESS-OFF

PO1B - PRESS-OFF ONE BED

KH - KNOT HOLE

SH - SLUB HOLE

D - DROPSTITCHES

MC - MACHINE CUT

TS - TUCK STITCHES

DR - DROPSTITCH RUN

NL - NEEDLELINE

TN - TUCK NEEDLE

RN - RIP NEEDLE

B - BARRE

S - SLUB $\geq$ 1CM. LONG

TTY - THICK/THIN YARN

FC - FIBRE CONTAMINATION

N - NEPS

K - KNOTS

DY - DIRTY YARN

FIGURE 16a

FEATURE TREE STRUCTURE - REGIONAL DEFECTS

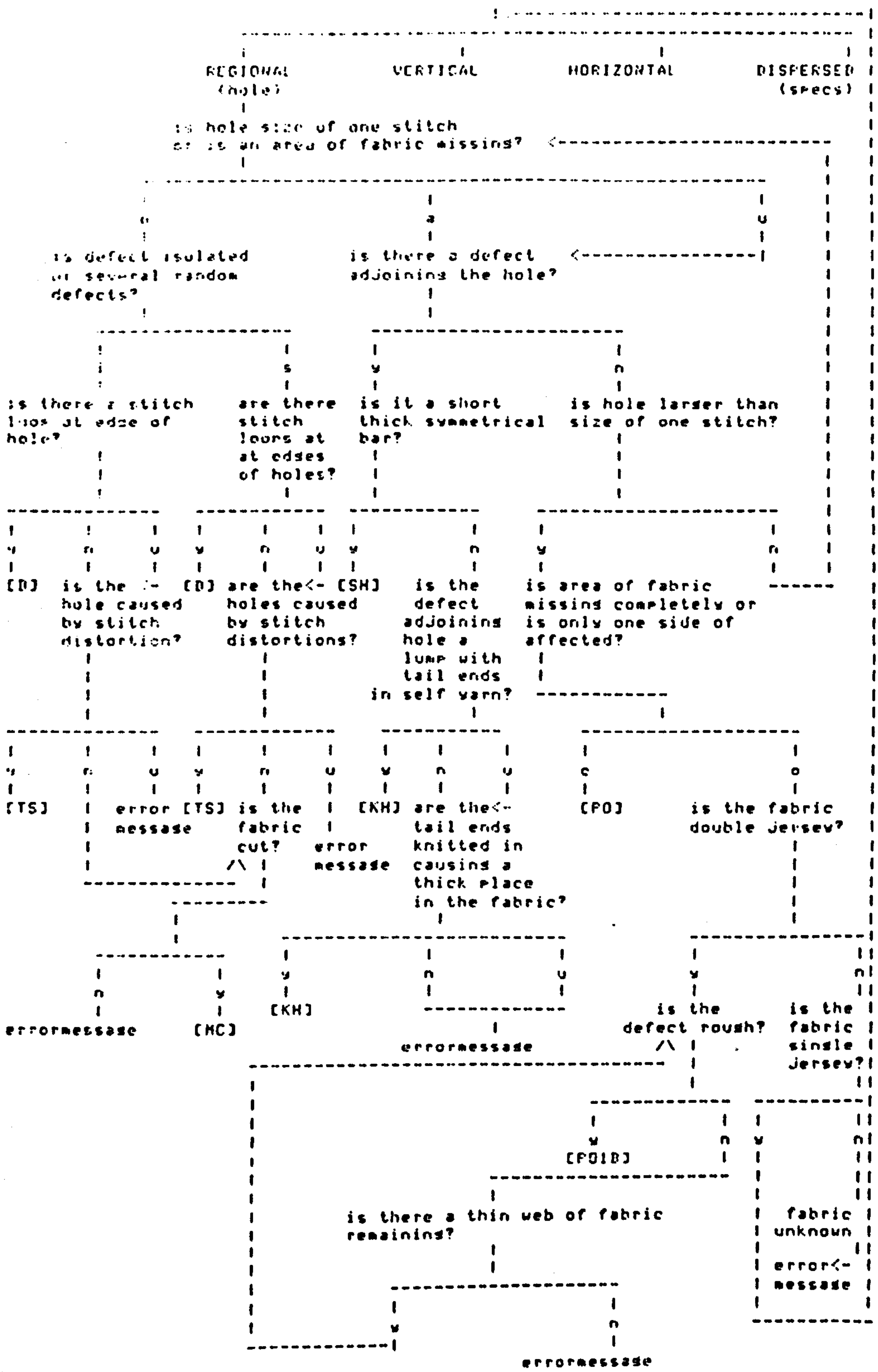


FIGURE 16b

FEATURE TREE STRUCTURE - VERTICAL DEFECTS

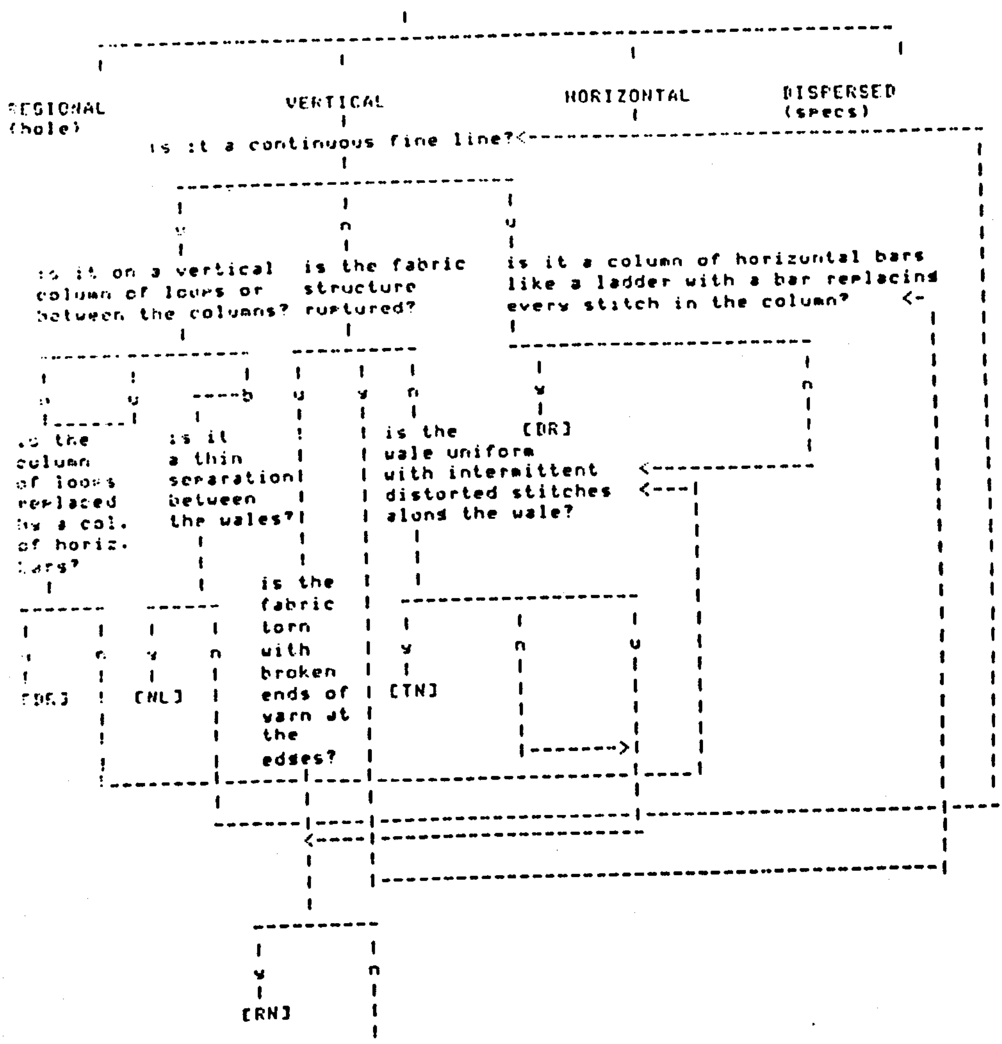


FIGURE 16c

FEATURE TREE STRUCTURE - HORIZONTAL DEFECTS

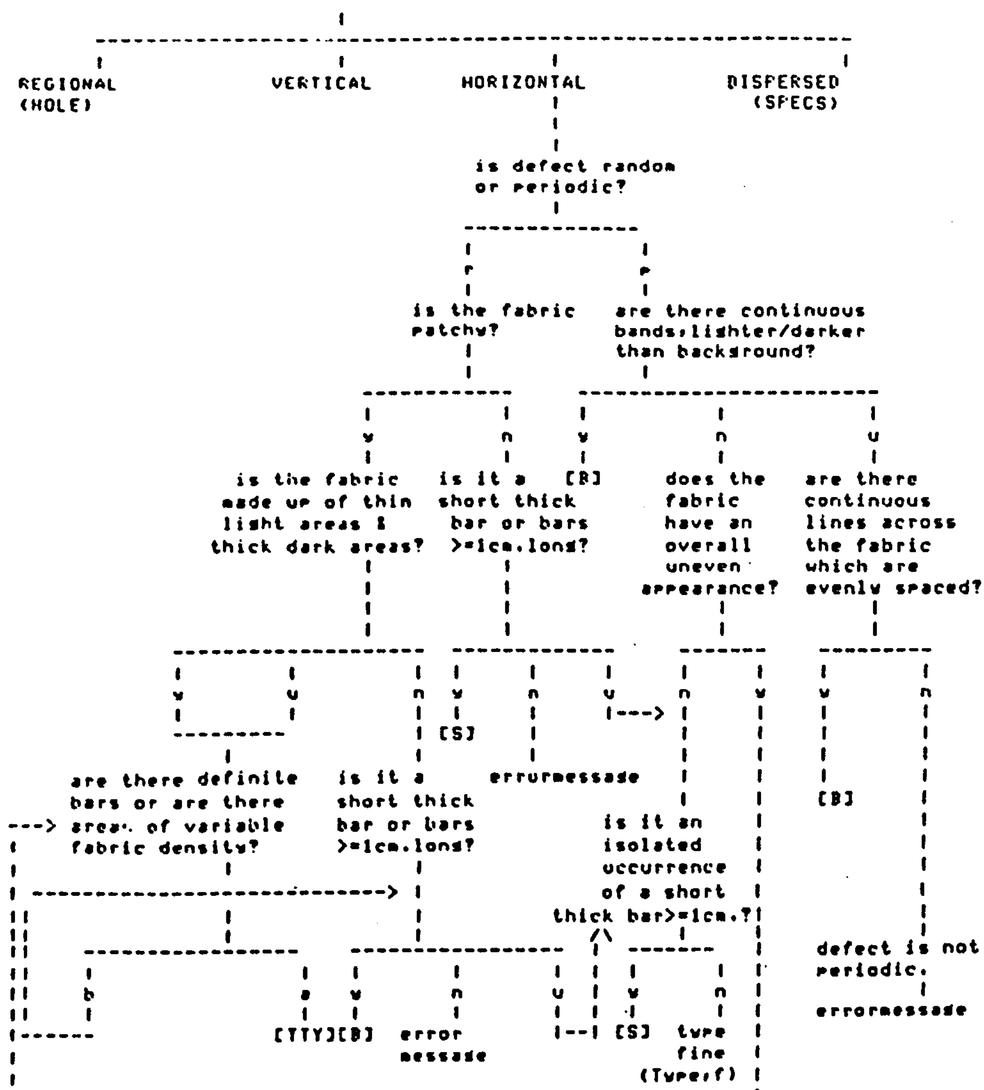
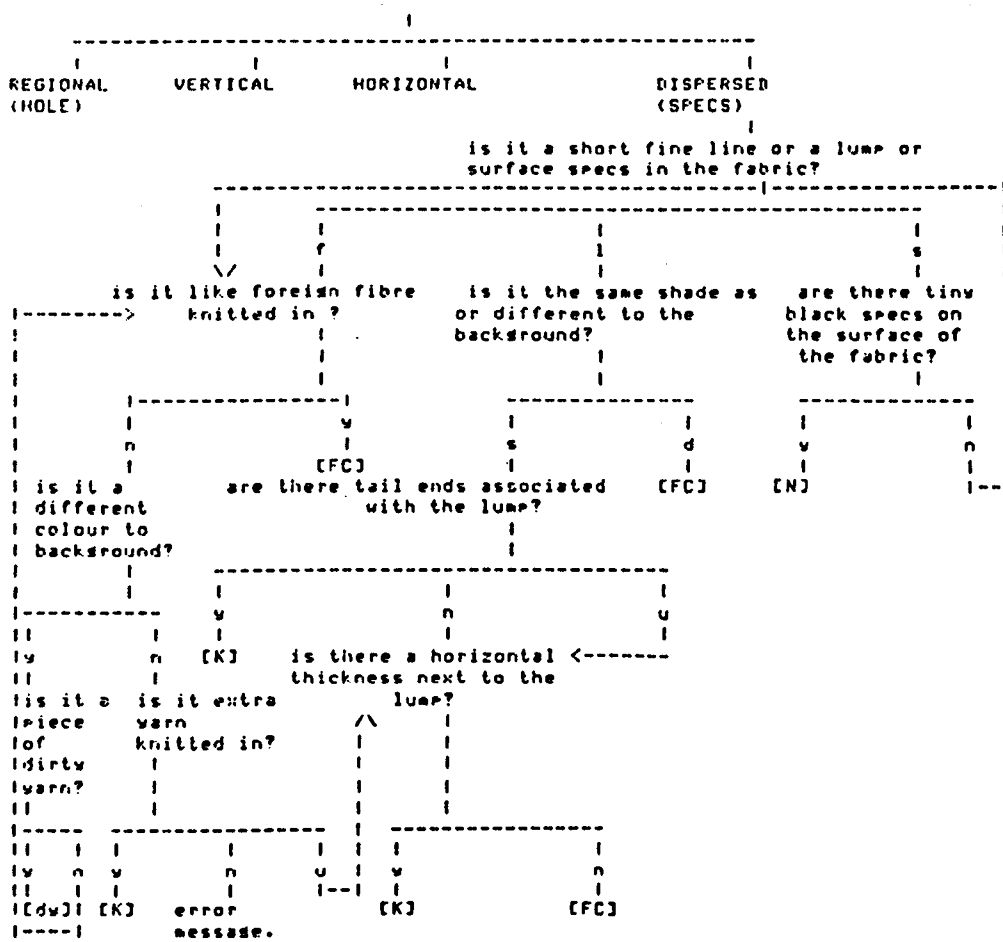


FIGURE 16d

FEATURE TREE STRUCTURE - DISPERSED DEFECTS



is proving to be very lengthy and employing too wide a vocabulary for a computer to realistically comprehend. Interfacing the database to the image processing system is complicated because each term used has to be interpreted for successful communication between the database and the image processing routines to occur.

7.4.2 FEATURE LIST APPROACH

The database shown in Figure 17 contains each defect with its respective set of features in list form. This approach includes not only visual features but introduces numerical values associated with length, width and diameter parameters.

Clearly, certain features are common to several defects. When such a feature is discounted during inspection, the number of possibilities and the size of the lists are effectively reduced so that identification occurs by a process of elimination. Where uncertainty exists and an 'unknown' response obtained, the uncertain feature remains in the list/s and the proceeding feature in the list checked.

A significant aspect of this approach allows the assignation of threshold values to defects such as neps and knots. A characteristic common to these defects in making accept/reject decisions is the number of occurrences of the defect within a specified area of fabric. These

FIGURE 17

DATABASE FOR FEATURE LIST APPROACH

```
/* database of defects and features with feature parameters */.

type (slub, [horizontal, [bar,5,20], thickening, 'self yarn',
['more than one defect in 10 sq.cm. fabric',2,20], random] ).

type (slub, [horizontal, [bar,5,75], thickening, 'self yarn',
'isolated occurrence'] ).

type (barre, [horizontal, [bar,100], 'self yarn', 'more than
1 bar', 'regular spaced'] ).

type (barre, [horizontal, lines, fullwidth, 'self yarn',
periodic, 'rows of tight stitching'] ).

type (barre, [horizontal, lines, fullwidth, 'self yarn',
periodic, 'rows of loose stitching'] ).

type (thick/thin, [horizontal, 'flash lines', 'self yarn',
areas of variable density', random] ).

type (needleline, [vertical, ['complete line',3,100] .
[narrow,0,1], ladder, straight] ).

type ('dropstitch run', [vertical, ['complete line',2,50],
[narrow,2,5], ladder, straight, 'horizontal strands'] ).

type ('tuck needle', [vertical, 'intermittent line', 'tiny
holes', 'stitch distortions'] ).

type ('rip needle', [vertical, 'intermittent line', 'large
holes'] ).
```

type ('press off', [regional, [hole, 3,50], circular, 'more than 2 stitches missing', random]).

type ('press off 1 bed', [regional, 'small ladders', 'not knitting on one bed', 'double jersey fabric', 'oval-shaped']).

type (dropstitches, [regional, [hole,1,3], circular, 'isolated occurrence of defect']).

type (dropstitches, [regional, [hole,1,3], circular, 'several occurrences of defect', random]).

type ('slub hole', [regional, [hole,1,15], 'thickening associated with the hole', random]).

type ('knot hole', [regional, [hole,1,15], 'lump associated with hole', 'tailends either knitted in or loose']).

type (knots, [dispersed, lump, ['more than 1 lump in 10 sq.cm. fabric',2,10], 'self yarn', random, 'tailends either knitted in or loose']).

type (neps, [dispersed, 'black specs', ['more than 1 black spec in 10 sq.cm. fabric',3,15], random, 'on the surface of the fabric']).

type ('fly contamination', [dispersed, lump, 'foreign fibre', 'different colour to background', ['more than 1 lump in 10 sq.cm. fabric',3,10]]).

type ('fly contamination', [dispersed, 'foreign fibre', 'different colour to background', ['short fine line',2,15]]).

tolerances can be modified to comply with manufacturer specifications.

One of the difficulties in standardising defect information is the variability in defect size. To overcome this problem, maximum and minimum values have been assigned to defects with length, width or diameter parameters. As part of an automated inspection system, once a feature with one or more of these parameters is detected, the image processing system supplies a numerical value to the database. If the value lies within the set tolerances, the feature is acknowledged.

In comparison, this approach is much quicker than the feature tree approach and allows the database to be easily modified or replaced by another of a similar structure. The program for the feature list database is shown in Appendix D.

To meet industrial requirements for an interactive system, a database of defect causes has been incorporated in this approach. Appendix E contains the program for the defect causes database.

An attractive property of this approach is the flexibility of the database which allows unbiased interaction between the image processing system and the database through the implementation of numerical values and thresholds.

Whilst the structure of the database is relatively less complex than the feature tree database, the vocabulary used remains unrestricted and is too wide to be efficiently interpreted by the computer system.

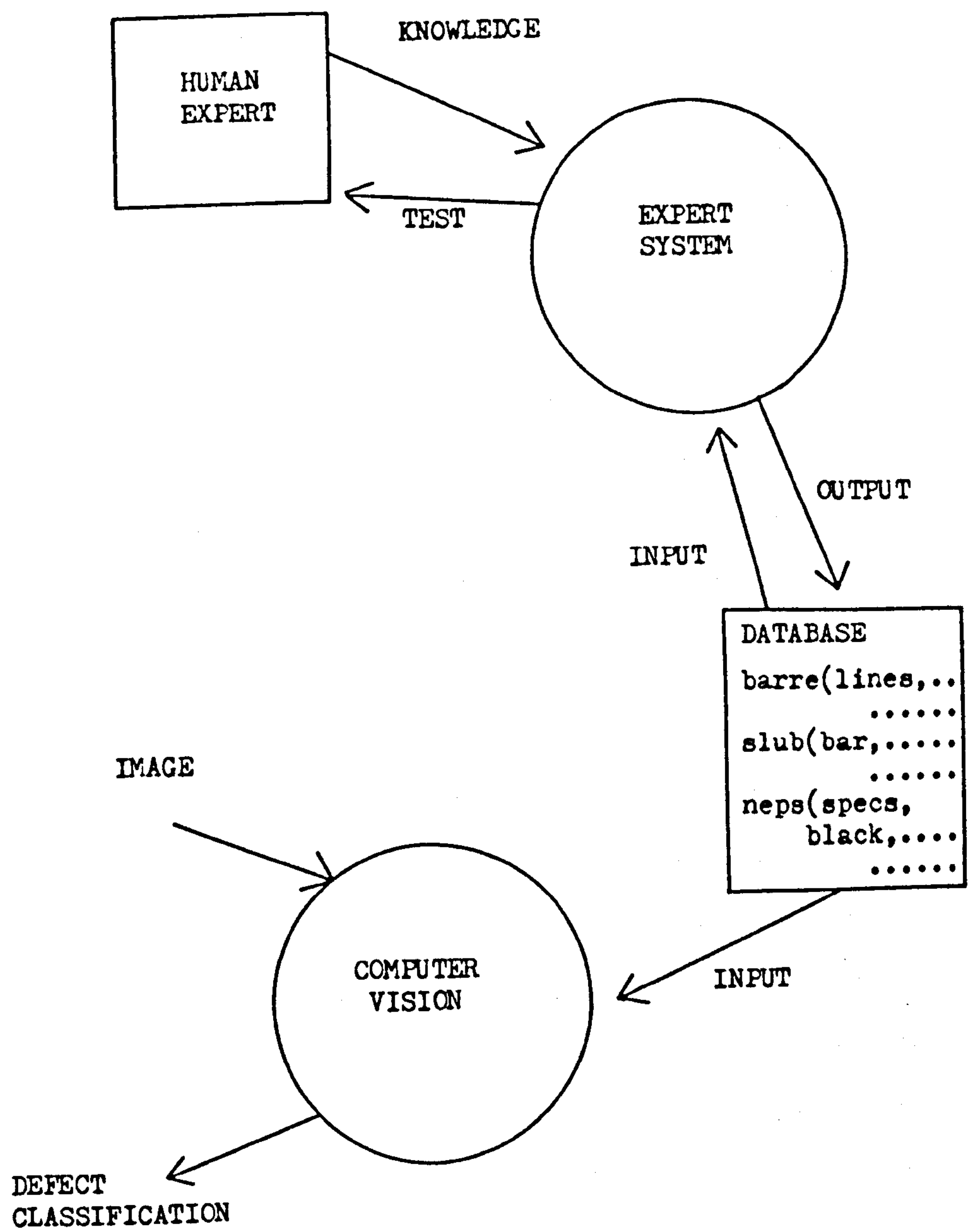
7.4.3 KNOWLEDGE-BASE DRIVEN IMAGE CLASSIFICATION APPROACH

Figure 18 illustrates the components of an intelligent knowledge-base inspection system. In this approach an expert system is used to create the database. Appendix F contains the program developed to generate the defects database. The most important components of this type of system are the application expert and the semantic processor. The interface between these two components is formed by the database. The database (Appendix F) must be sufficiently 'English-like' to be written by the textile expert and yet be readily interpreted by both the expert system used to develop it and the semantic processor. Numeric parameters form an important characteristic of feature description, the expert system being responsible for converting the human (subjective) view into a more computer-tangible form. The human expert's input vocabulary is not necessarily restricted as the program contains synonym lists to accommodate a number of like terms e.g. round, circle, circular.

As a progressive development, this approach incorporates the feature list program and database as a test facility for the new database. In a similar way, the cause of defects as shown in Appendix E, is included. On

FIGURE 18

AN INTELLIGENT KNOWLEDGE-BASE SYSTEM



classification of a defect, the causes and remedial actions at source are automatically supplied, providing an information feedback facility.

In consideration of all three approaches to database development, the knowledge-base image classification approach is the most objective in that the input parameters are not set and the database is an adaptive one in terms of its progressive development. The use of this approach is potentially very powerful, particularly when combined with an expert system for database development. Refinement of semantic processor and expert system software makes possible the development of an efficient image processing system by a computer-naive/application-expert.

7.5 IKB SYSTEM IMPLEMENTATION

The successful implementation of an IKB System in an industrial environment is measured by performance. In the development of real-time image processing equipment, the architecture largely determines the limits to performance. Conventional computer architecture such as the prototype image processing system used for the research, allows only one operation to be performed on a single data element at a given instant. The speed with which serial processing can be carried out is limited by the rate at which data can be read from memory. To achieve processing of sufficient performance for an industrial machine vision system necessitates considerable improvements in memory speed. For the large memory capacity required in image processing, this is currently impractical. The alternative is to employ a parallel processing system capable of high speed detection on moving webs of material such as knitted fabric. Most of the fabric surface area is free of defects and regions where detection routines indicate the presence of a defect can be extracted and processed at high speed.

7.6 SUMMARY

To summarise, chapter 7 is concerned with the integration of human knowledge into a computer system. Three components of an IKBS are identified and three approaches to the progressive development of the defects database component are discussed. The research tool employed for the development of defect detection algorithms and defects database programs is described. For implementation of an automated industrial vision system, performance in a real-time environment is a major criterion. It is concluded that a system with conventional computer architecture will not meet this requirement, consequently, a parallel processing system is proposed.

CHAPTER 8

OVERVIEW AND FURTHER RESEARCH

He will be our guide even to the end.

Psalm 48:14

8.0 Chapter 8 presents an overview of the application of automated fabric inspection in the Knitwear Industry. The software developed, as part of the research, towards an automated inspection system is discussed and areas for refinement proposed. Two major areas of current interest to the Knitwear Industry are, firstly, the inspection of cut fabric pieces for automatic garment make-up and, secondly, automated garment inspection. The work conducted to date forms the foundations for further research, creating in-roads into these new areas and leading to a widespread application of automated inspection throughout the Knitwear manufacturing route.

8.1 INTRODUCTION

An overview of the Knitwear Industry, clearly illustrates the current lack of commercial automated inspection equipment in general throughout the Industry. Furthermore the economic pressures of the past have not been sufficiently strong to bring about large-scale automation. More recently, with worsening economic conditions, the manufacturers' viewpoint has changed. Research and development in production methods are welcomed, the aim being to reduce costs wherever possible. It is noteworthy that advances in various production operations have not been concurrent. The earliest advances in automation have occurred in operations such as knitting, dyeing and finishing and cutting, the automation of inspection being a later development. Without doubt, production operations in a garment manufacturing route are interdependent. Technological change to one operation cause a 'knock-on' effect, perpetuating the need for improvements in other related processes.

8.2 OVERVIEW OF THE WORK

Visual inspection of textile materials is developing as an important aspect of automatic technology, since it offers fast, contactless sensing of a wide variety of defects, many of which cannot be detected effectively by other mechanical means. To implement a system in an industrial environment, automated visual inspection involves several quite different branches of technology, including:

- MECHANICAL HANDLING OF FABRICS (ROBOTICS),
- ILLUMINATION AND VIEWING TECHNIQUES

In visual inspection of fabrics the quality of lighting is paramount. Inadequate lighting may cause key features to be obscured by glare or the intensity of light reaching the detector may be insufficient. For inspection of tubular knitted fabrics, it is necessary to have an evenly illuminated form over which the fabric tube is extended. Choice of illumination depends to some extent on the image processing detection algorithms used. The effects of varying the lighting can be quite spectacular, influencing the overall performance of an inspection system significantly,

- IMAGE CAPTURE TECHNIQUES

For on-line inspection where the fabric is moving in excess of 40 metres/minute, by scanning across the direction of motion using line-scan cameras, a picture can be built up line by line as the object passes the inspection station. To view the total width of fabric in the tube requires a multi-camera arrangement. It is envisaged that between 4 and 6 line-scan cameras will be employed, 6 cameras covering an open width of approximately 90 cms,

- ELECTRONICS,
- COMPUTER ARCHITECTURE AND SOFTWARE,
- EXPERT KNOWLEDGE ACQUISITION AND INTEGRATION.

The development of an interactive computer system to perform the inspection task consists of combining the perceptual skills and intelligence of human experts with the manipulative ability of the machine. This research has focussed on the acquisition of knowledge required for defect recognition and classification and integrating the information into a defects database. This application represents a significant and novel approach to the automation of the fabric inspection process.

The database developed forms one of the basic components of the system proposed for automated inspection - an intelligent knowledge-base system. The software developed has shown the following:

1. for an effective environment in which to tackle

complex defect recognition and classification problems, the software has to be developed to provide the maximum facilities in a flexible but easy to use form.

2. whilst all branches of technology involved in the development of an automated fabric inspection system are important, it is the software which dictates how much of the potential in any hardware system is eventually realised.

3. the commercial implementation of an automated fabric inspection system is within reach of both the hardware and the software available.

Speed is of paramount importance to the design of an industrial inspection system, implementation of the detection algorithms on a parallel processing computer system shows that the software can be written to operate at sufficient speed for industrial fabric inspection. The software has been developed using expensive computer equipment. This work lays the foundation for the development of a cheaper, dedicated automated fabric inspection system.

8.3 REFINEMENTS

One stage towards extending the usefulness of the data - or knowledge-base may be achived by measuring the consequence of an unsuccessful recognition. Uppermost, defect detection must be 100% efficient to be industrially viable. The requirements for defect recognition are not necessarily so stringent. The defect types and features contained in the knowledge-base constrain the system to known types of results, the performance being dependent on the efficiency and consistency of the information supplied by the expert. System performance can be measured through the defect statistics obtained. Where the ~~significance~~ rate of occurrence of a defect is known and recognition of the defect is unsuccessful, the performance of the system is effectively reduced by that figure. Similarly, the efficiency of defect feature recognition may be monitored.

Using the knowledge-base driven image classification approach, an automatic monitoring and adaptive knowledge-base may be developed. In this way, the detected features are stored in a separate knowledge-base and the feature list tested against the equivalent feature list in the original knowledge-base. The original knowledge-base may then be refined by removal of features or by transferring additional features from the new knowledge-base to the original one.

Another area of software refinement is to provide an on-going analysis of fault occurrence with a view to detecting trends, for example machine and yarn variability so that preventative action may be taken.

Further work is required with industry to refine the defect causes program. For certain defects there are a large number of possible causes suggested which are unranked in order of likelihood. Clearly, feedback plays an important role in industrial manufacturing processes for reducing fabric wastage. This is particularly effective in cases where inspection immediately follows the knitting process. To rank the possible causes and remedial actions at source in order of priority is imperative for optimum use of the system.

8.4 FURTHER RESEARCH

An area of growing interest to the Knitwear Industry is the automation of garment make-up. As part of this development the automated inspection of cut pieces is required which involves the following parameters:

1. fabric defect recognition.
2. measurement of dimensions.
3. orientation.

The work undertaken fulfills the first requirement for this application, additional research is required to establish sizing and robotic handling requirements.

Fabric inspection is not an independent process but is one in an associated chain of operations to manufacture an end product. Any change in one or more of the operations must be compatible with other operations in the manufacturing route. Yet another inspection operation in the manufacture of knitted garments is that of garment inspection. Garment inspection is a process with worldwide applications but, to date, very few technological advances have been made in this area.

The inspection of a garment is not dissimilar to fabric inspection in that both rely heavily on a human examiner and both demand fabric defect detection and identification. Differences lie in the handling and presentation of the item for inspection and also garment inspection encompasses a wider range of parameters for examination. The three broad parameters involved in inspection of a garment are as follows:

1. fabric defect recognition.
2. garment measurement and sizing.
3. determination of position point (aesthetics).

Areas of study for further textile research include the determination of industrial requirements of garment inspection and a series of industrial surveys in order to establish size specifications and position points for pocket plackets and other trims.

8.5 SUMMARY

An important facet of the research work is its applicability to other manufacturing operations such as garment make-up and garment inspection. The knowledge-base image classification approach developed for an intelligent knowledge-base inspection system is potentially powerful due to its universal appeal. Not only is automated fabric inspection a viable proposition for Industry but a major step has been taken towards the solution of a more complex problem - the automation and application of garment inspection in the Knitwear Industry.

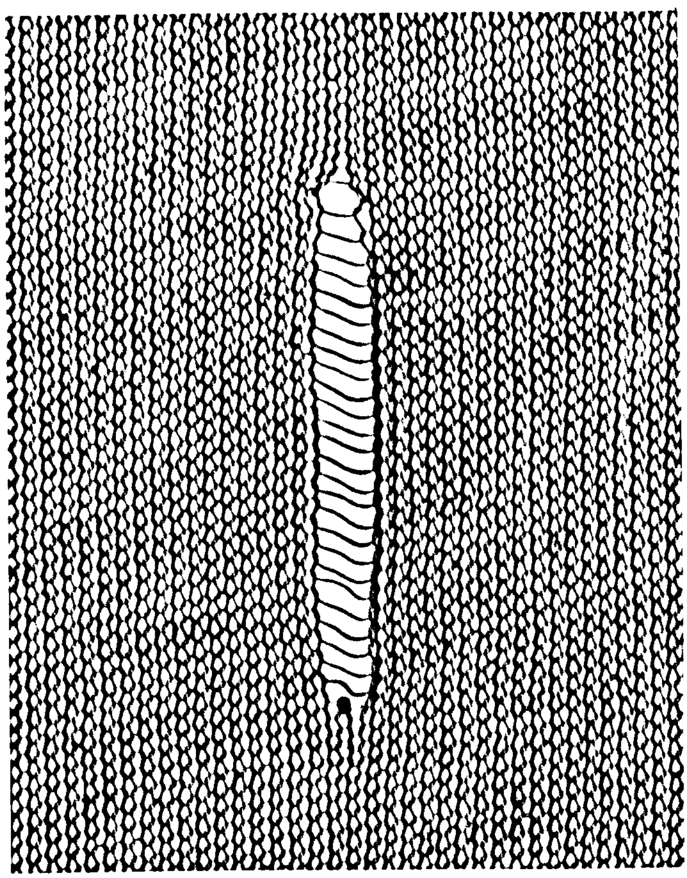
APPENDIX A

DETAILS OF INSPECTION METHODS EMPLOYED BY COMPANIES INVOLVED IN INDUSTRIAL SURVEY

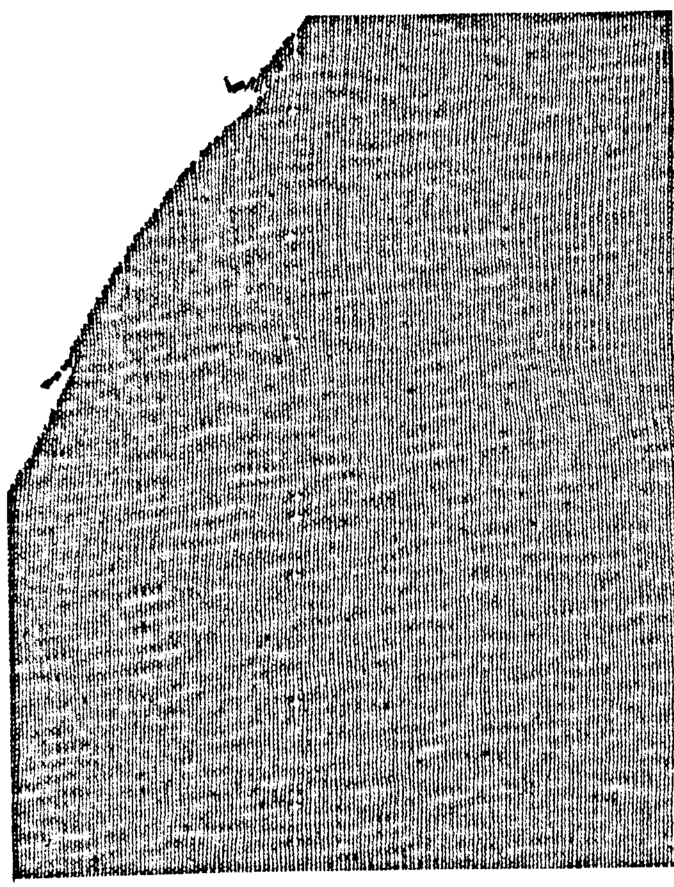
METHOD OF FABRIC INSPECTION	TYPE	FIGURE NUMBER
1	FABRIC INSPECTION MACHINE WITH ROLLER ARRANGEMENT	6
2	MANUAL INSPECTION TABLE	5
3	OPEN-WIDTH FABRIC INSPECTION MACHINE	8
4	FABRIC INSPECTION MACHINE WITH MIRROR ARRANGEMENT	7

APPENDIX B

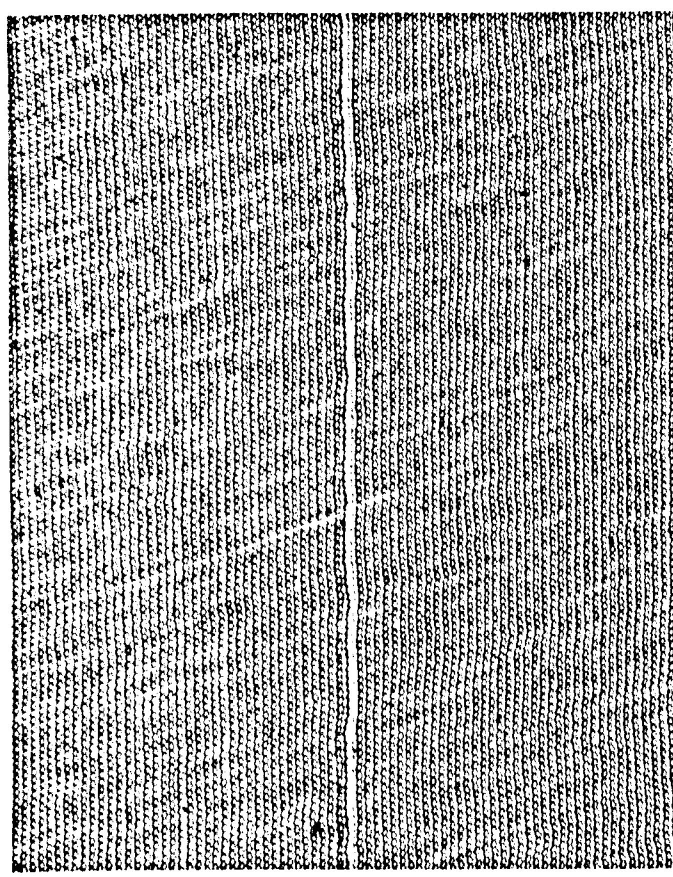
PHOTOGRAPHS OF EXAMPLES OF DEFECTS



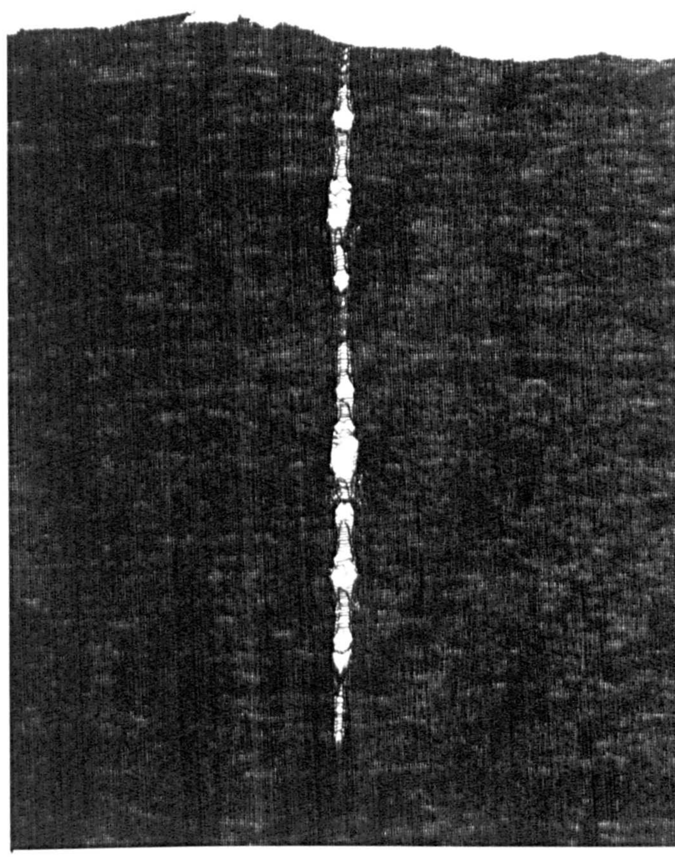
DROPSTITCH RUN



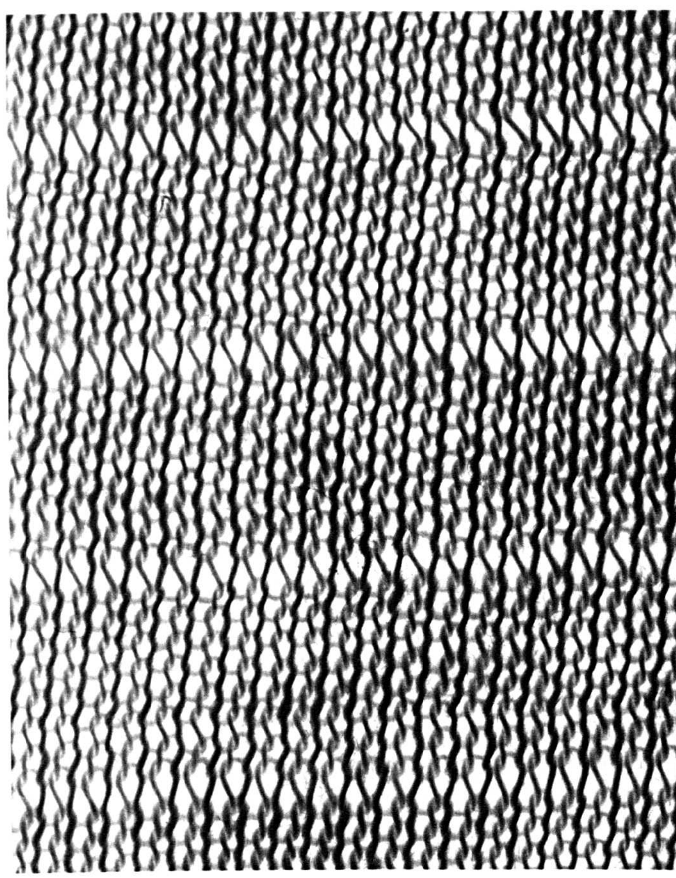
TUCK NEEDLE



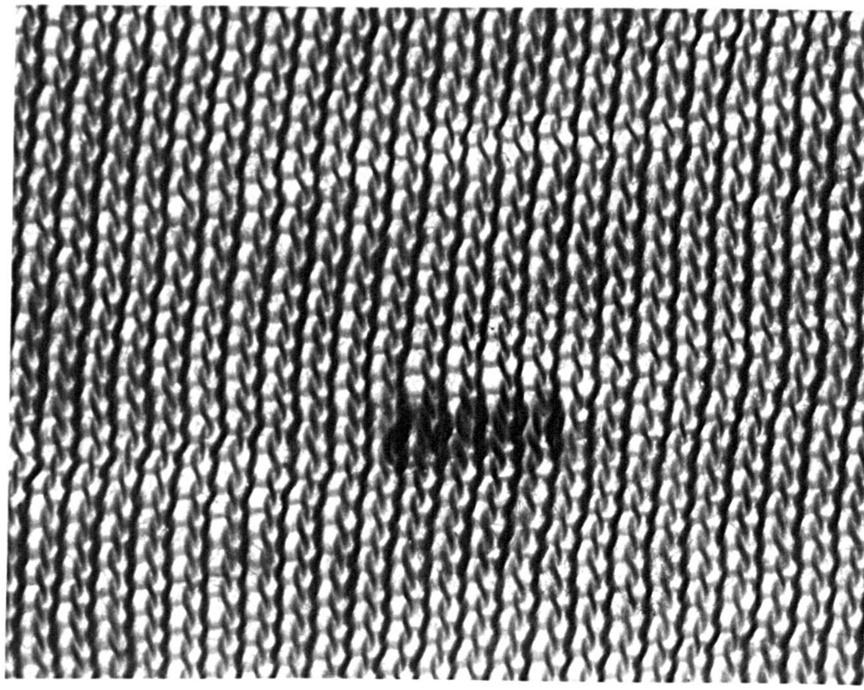
NEEDLELINE



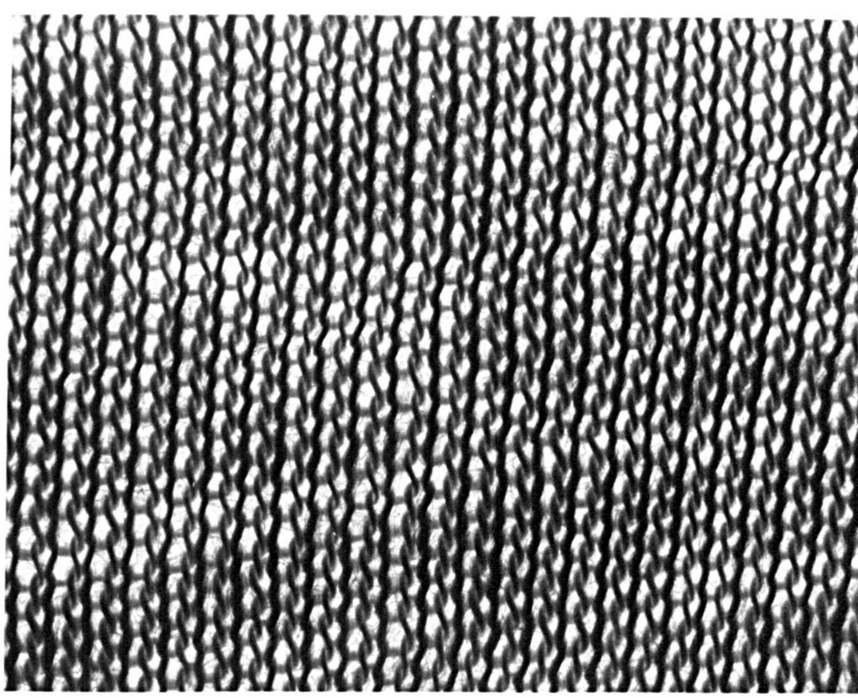
RIP NEEDLE



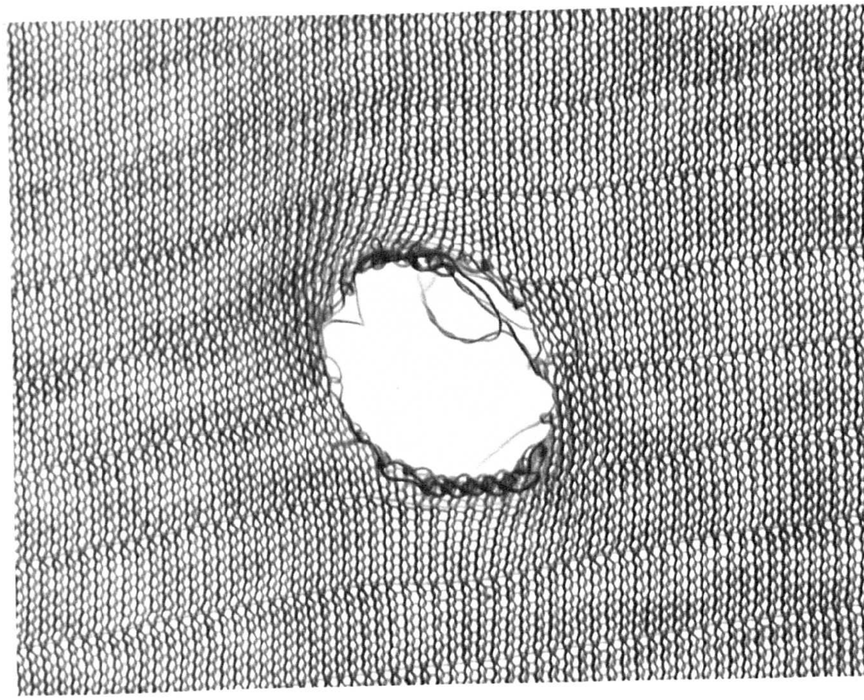
BARRE



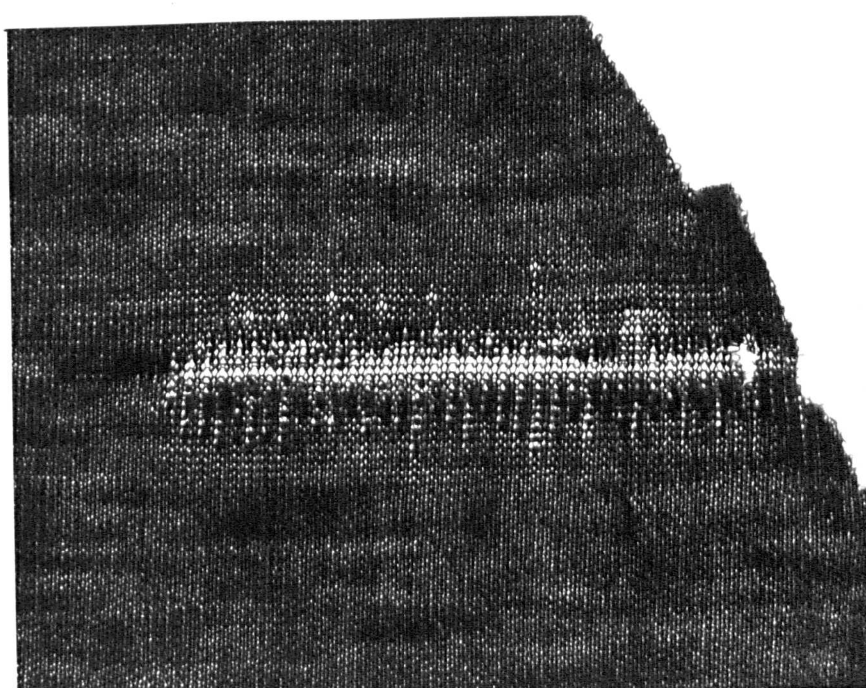
SLUB>=1CM



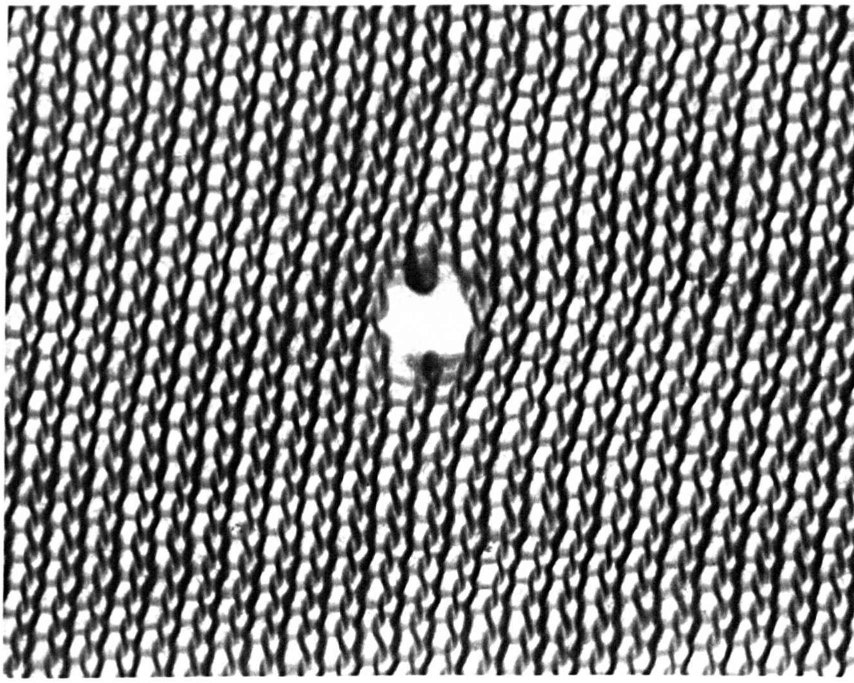
THICK/THIN YARN



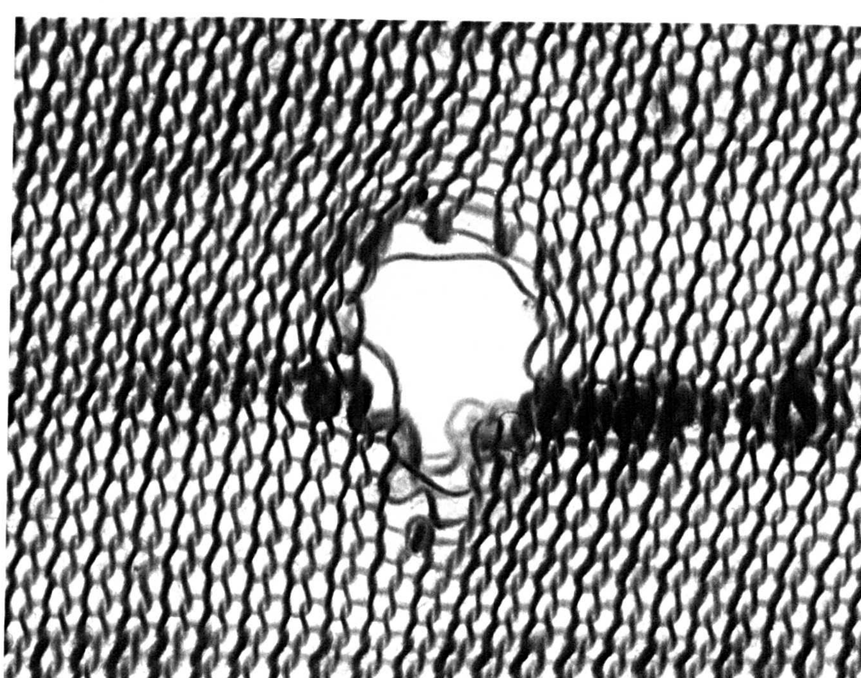
PRESS OFF



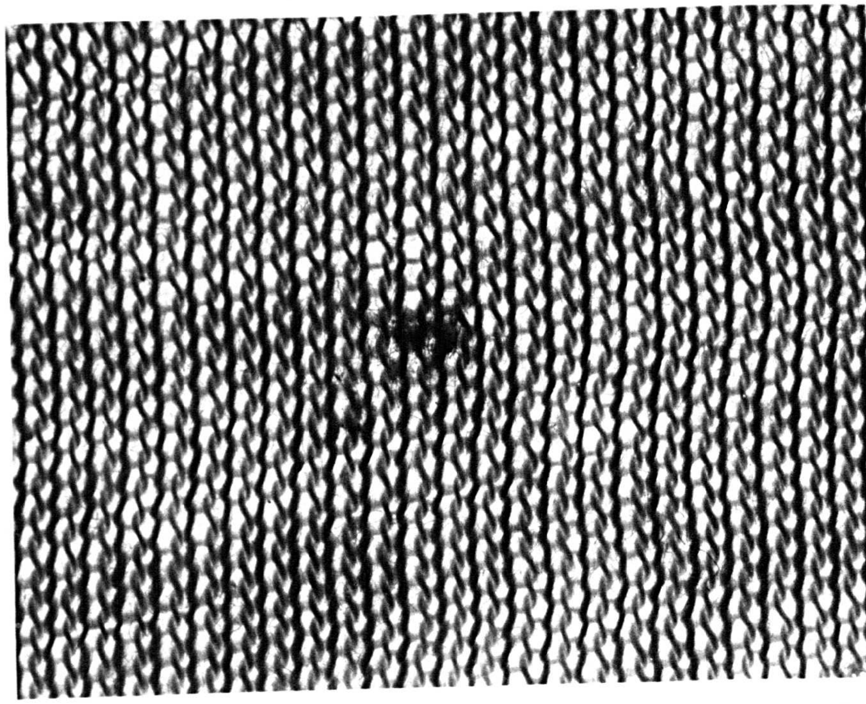
PRESS OFF 1 BED



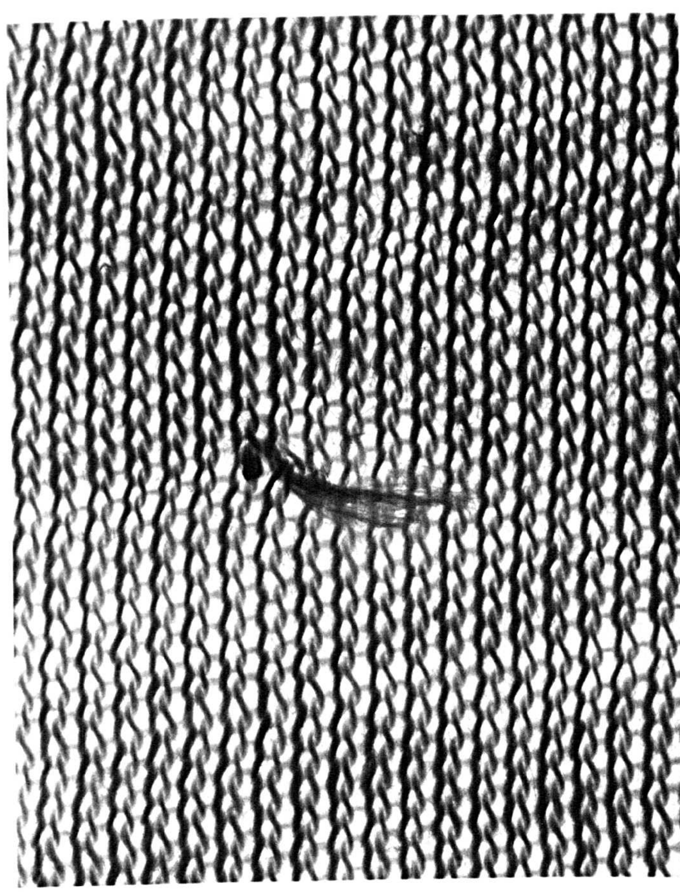
DROPSTITCHES



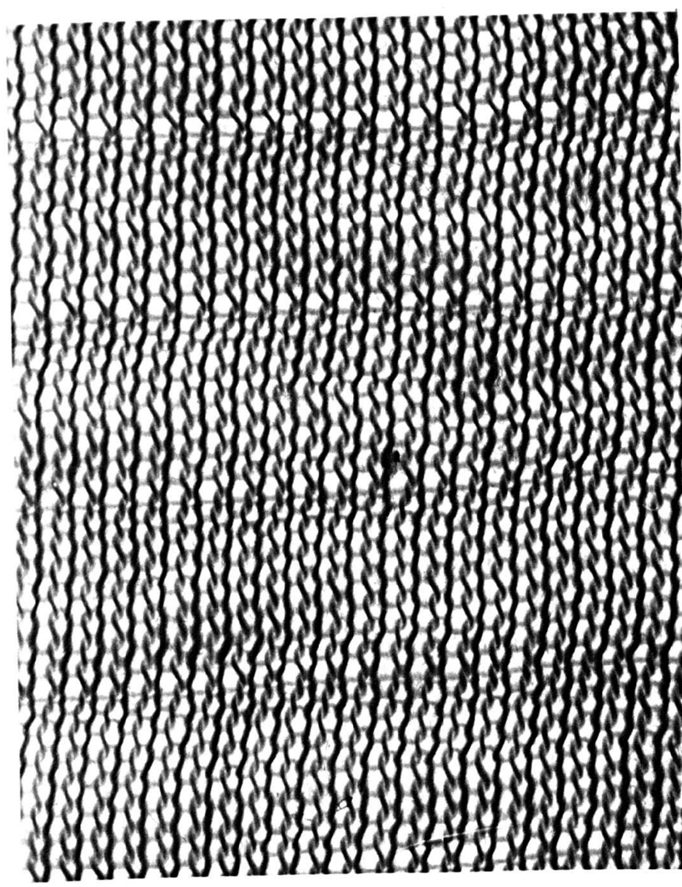
SLUB HOLE



FIBRE CONTAMINATION



KNOT



NEPS

APPENDIX C

FEATURE TREE DEFECT CLASSIFICATION PROGRAM

```
help:-nl,write('the start command is    ?-  defect.       ')

defect:-
write('is it regional(hole),vertical,horizontal,dispersed(specs)
(r,v,h,d)?'),read(X),nl,defectclass(X,Type),nl,write(Type).

defectclass(r,Type):-
write('is hole size of one stitch or is an area of fabric missing
(o,a,u)?'),read(Onest),typeonest(Type,Onest).

typeonest(Type,o):-
write('is defect isolated or several random defects(i,s)?'),read
(Isol),typeisol(Type,Isol).

typeonest(Type,a):-
write('is there a defect adjoining the hole(y,n)?'),read(Defad),
typedefad(Type,Defad).

typeonest(Type,u):-not(eq(B,o)),not(eq(B,a)),typeonest(Type,a).

typeisol(Type,i):-
write('is there a stitch loop at the edge of the hole(y,n,u)?'),
read(Loop),typeloop(Type,Loop).

typeisol(Type,s):-
write('is there a stitch loop at the edge of the holes(y,n,u)?'),
read(Hole),typehole(Type,Hole).

typedefad(Type,y):-
write('is defect adjoining the hole a short,thick symmetrical bar
(y,n)?'),read(Short),typeshort(Type,Short).

typedefad(Type,n):-
write('is hole larger than size of one stitch(y,n)?'),read(Large),
typelarge(Type,Large).

typeloop(Type,y):-write('defect is a dropstitch').

errormessage:-write('defect unknown check input data').

typeloop(_,?):-errormessage.

typeloop(Type,n):-
write('is the hole caused by a stitch distortion(y,n,u)?'),read
(Distort),typedistort(Type,Distort).
```

```
type(Type,u):-not(eq(B,y)),not(eq(B,n)),typeloop(Type,n).

type(Type,y):-wr_te('defects are dropstitches').

typehole(Type,n):-
write('are the holes caused by stitch distortions(y,n,u)?'),read
(Dust).

type(Type,Dust).

typehole(Type,u):-not(eq(B,y)),not(eq(B,n)),typehole(Type,n).

typeshort(Type,y):-write('defect is a slub hole').

typeshort(Type,n):-
write('is the defect adjoining the hole a lump with tail ends in self
yarn(y,n,u)?'),read(Lump),typelump(Type,Lump).

typelarge(Type,y):-
write('is the area of fabric missing completely or is only one side of
the fabric affected(c,o)?'),read(Comp),typecomp(Type,Comp).

typecomp(Type,c):-write('defect is a press-off').

typecomp(Type,o):-
write('is the fabric double jersey rib(y,n)?'),read(Rib),typerib
(Type,Rib).

typerib(Type,y):-
write('is the surface rough(y,n)?'),read(Rough),typerough(Type,Rough).

typerib(Type,n):-
write('is the fabric single jersey(y,n)?'),read(Sing),typesing
(Type,Sing).

typerough(Type,y):-write('defect is a press off on one bed').

typerough(Type,n):-
write('is there a thin web of fabric remaining(y,n)?'),read(Web),
typeweb(Type,Web).

typesing(Type,y):-defectclass(r,Type).

typesing(Type,n):-write('fabric structure unknown'),nl,errormessage.

typeweb(Type,y):-typerough(Type,y).

typeweb(Type,n):-errormessage.

typelarge(Type,n):-defectclass(r,Type).

typedust(Type,y):-write('defects are tuck stitches').
```

```
typedust(Type,n):-write('is the fabric cut(y,n)?'),read(Cut),
                  typecut(Type,Cut).

typedust(Type,u):-errormessage.

typelump(Type,y):-write('defect is a knot hole').

typelump(Type,n):-
write('are the tail ends knitted in causing a thick place in the
fabric(y,n,u)?'),read(Knit),typeknit(Type,Knit).

typelump(Type,u):-typelump(Type,n).

typecut(Type,y):-write('defect is a machine cut').

typecut(Type,n):-errormessage.

typedistort(Type,y):-write('defect is a tuck stitch').

typedistort(Type,n):-typedust(Type,n).

typedistort(Type,u):-not(eq(B,y)),not(eq(B,n)),errormessage.

errormessage:-write('defect unknown check input data').

typeknit(Type,y):-write('defect is a knot hole').

typeknit(Type,n):-errormessage.

typeknit(Type,u):-errormessage.

defectclass(v,Type):-
write('is it a continuous fine line(y,n,u)?'),read(Fine),typefine
(Type,Fine).

typefine(Type,y):-
write('is it on a vertical column of loops or between the columns
(o,b,u)?'),read(Col),typecol(Type,Col).

typefine(Type,n):-
write('is the fabric structure ruptured(y,n,u)?'),read(Rupt),
typerupt(Type,Rupt).

typefine(Type,u):-
write('is it a column of horizontal bars,like a ladder,with a bar
replacing every stitch in the column(y,n)?'),read(Like),typelike
(Type,Like).

typecol(Type,o):-
write('is the column of loops replaced by a column of horizontal bars
(y,n)?'),read(Rep),typerep(Type,Rep).
```

```
typecol(Type,b):-
write('is it a thin separation between the wales(y,n)?'),read(Sep),
typesep(Type,Sep).

typecol(Type,u):-typecol(Type,o).

typerupt(Type,y):-typefine(Type,u).

typerupt(Type,n):-
write('is the wale uniform with intermittent stitches along the wale
being distorted(y,n,u)?'),read(Unif),typeunif(Type,Unif).

typerupt(Type,u):-
write('is the fabric torn with broken ends of yarn at the edges
(y,n)?'),read(Torn),typetorn(Type,Torn).

typelike(Type,y):-write('defect is a dropstitch run').

typelike(Type,n):-typerupt(Type,n).

typerep(Type,y):-typelike(Type,y).

typerep(Type,n):-typerupt(Type,n).

typesep(Type,y):-write('defect is a needleline).

typesep(Type,n):-defectclass(v,Type).

typeunif(Type,y):-write('defect is a tuck needle').

typeunif(Type,n):-typerupt(Type,u).

typeunif(Type,u):-typecol(Type,b).

typetorn(Type,y):-write('defect is a rip needle').

typetorn(Type,n):-errormessage.

defectclass(h,Type):-
write('is it random or periodic(r,p)?'),read(Rand),typerand(Type,Rand).

typerand(Type,r):-
write('is the fabric patchy(y,n)?'),read(Patch),typepatch(Type,Patch).

typerand(Type,p):-
write('are there continuous bands lighter/darker than the background
(y,n,u)?'),read(Bands),typebands(Type,Bands).

typepatch(Type,y):-
write('is the fabric made up of thick dark areas and thin light areas
(y,n,u)?'),read(Areas),typeareas(Type,Areas).

typepatch(Type,n):-
write('is it a short thick bars or bar>=1 cm.long(y,n,u)?'),read
(Bars),typebars(Type,Bars).
```

```
typebands(Type,y):-write('defect is barre').

typebands(Type,n):-
write('does the fabric have an overall uneven appearance(y,n)?'),
read(Uneven),typeuneven(Type,Uneven).

typebands(Type,u):-
write('are there continuous lines across the fabric which are equally
spaced(y,n)?'),read(Space),typespace(Type,Space).

typeareas(Type,y):-typeareas(Type,u).

typeareas(Type,n):-
write('is it short thick bars >=1 cm.long(y,n,u)?'),read(Bars),
typebars(Type,Bars).

typeareas(Type,u):-
write('are there definite bars or are there areas of variable fabric
density(b,a)?'),read(Defi),typedefi(Type,Defi).

typebars(Type,y):-write('defect is a slub/s').

typebars(Type,n):-errormessage.

typebars(Type,u):-typeuneven(Type,n).

typeuneven(Type,y):-typeareas(Type,u).

typeuneven(Type,n):-
write('is it an isolated occurrence of a short thick bar> =1 cm.
(y,n)?'),read(One),typeone(Type,One).

typespace(Type,y):-typebands(Type,y).

typespace(Type,n):-
write('defect is not periodic'),nl,errormessage.

typedefi(Type,b):-typeareas(Type,n).

typedefi(Type,a):-write('defect is thicknthin yarn').

typeone(Type,y):-typebars(Type,y).

typeone(Type,n):-typefine(Type,f).

defectclass(d,Type):-
write('is it a short fine line or a lump or surface specs on the fabric
(f,l,s)?'),read(Fine),typefine(Type,Fine).

typefine(Type,f):-
write('is it like a foreign fibre knitted in(y,n)?'),read(Diff),
typediff(Type,Diff).
```

```
typefine(Type,l):-
write('is it the same colour or different to the background(s,d)?'),
read(Same),typesame(Type,Same).

typefine(Type,s):-
write('are there tiny black specs on the surface of the fabric(y,n)?'),
read(Tiny),typetiny(Type,Tiny).

typediff(Type,y):-write('defect is fibre contamination').

typediff(Type,n):-
write('is it a different colour to the background(y,n)?'),read(Back),
typeback(Type,Back).

typesame(Type,s):-
write('are there tail ends associated with the lump(y,n,u)?'),read
(Ends),typeends(Type,Ends).

typesame(Type,d):-
write('defect is fibre contamination').

typetiny(Type,y):-write('defect is neps').

typetiny(Type,n):-typefine(Type,f).

typeback(Type,n):-
write('is it extra yarn knitted in(y,n,u)?'),read(Extra),typeextra
(Type,Extra).

typeback(Type,y):-
write('is it a piece of dirty yarn(y,n)?'),read(Dirt),typedirt
(Type,Dirt).

typeends(Type,y):-write('defect is a knot').

typeends(Type,n):-
write('is there a horizontal thickness next to the lump(y,n)?'),
read(Hor),typehor(Type,Hor).

typeends(Type,u):-typeends(Type,n).

typeextra(Type,y):-write('defect is a knot').

typeextra(Type,n):-errormessage.

typeextra(Type,u):-typeends(Type,u).

typedirt(Type,y):-write('defect is dirty yarn').

typedirt(Type,n):-typefine(Type,f).

typehor(Type,y):-write('defect is a knot').

typehor(Type,n):-typediff(Type,y).
```

APPENDIX D

FEATURE LIST DEFECT CLASSIFICATION PROGRAM

```
/* DEFKNIT.PRO */

go:-match([]).
match( Featurest ):-find( Featureset ),prnt.

find(_):-type(A,B),assertz(option(A,B)),fail.

/*purge option list to find minimum number of alternatives*/
  find(_):-quest,nl,write('alternatives are.....').

/*print alternatives*/
prnt:-found(X),nl,write(X),nl,cause(X),nl,nl,retract( found(X) ),fail.
prnt:-option(X,_),nl,write(X),nl,cause(X),nl,retract( option(X,_) ),fail.
prnt.

show:-option(X,Y),write(X),write(Y),nl,fail.

/*reduce options by asking questions*/

quest:-option(X,[Q|T]),option(Y,_),not(eq(X,Y)),notall(Q),sap(Q),
      quest.
quest:-option(X,[Q|T]),zap(Q),quest.
quest:-option(X,_),assertz(found(X)),retract(option(X,_)),fail.
quest.

zap(Q):-ask(Q,A,V),xexecute(A,Q,V),deleteall(Q).

notall([Q|_]):-option(Z,L),not(member([Q|_],L)).
notall(Q):-option(Z,L),not(member(Q,L)).

/*ask question*/

ask(Q,A,V):-atom(Q),write('is the following true...y/n/x '),write(Q),
           write('? '),read(A).
ask([Q|P],A,V):-write('is the following feature present...y/n/x '),nl,
                nl,write(' '),write(Q),write('? '),read (A),((A=y,nl,
                write('enter the value (minimum 1,maximum 100)'),read
                (V),nl);nl).

/*   handle answer to question    */

xexecute(y,Q,V):-atom(Q),option(X,L),not(member(Q,L)),retract
                (option(X,L)),!,xexecute(y,Q,V).

xexecute(y,[Q|P],V):-option(X,L),(not member([Q|_],L;outrange(Q,V,L)),
                     retract(option(X,L)),!,xexecute(y,[Q|P],V).
```

```
outrange(Q,V,L):-member([Q|T],L),compare(T,V,A),!,A=n.

/* execute NO response....delete options not containing question*/

xexecute(n,Q,_):-atom(Q),option(X,L),member(Q,L),retract(option(X,L)),
                !,xexecute(n,Q,_).
xexecute(n,[Q|_],_):-option(X,L),member([Q|_],L),retract(option(X,L)),
                !,xexecute(n,[Q|_],_).

xexecute(_,Q,_):-deleteall(Q).
xexecute([,_,]).

deleteall(Q):-atom(Q),option(Z,L),member(Q,L),list(Q,Lq),subtract
         (L,lq,Newl),retract(option(Z,L)),assertz(option
         (Z,Newl)),!,deleteall(Q).

deleteall([Q|_]):-option(Z,L),member([Q|_],L),subtract(L,[[Q|_]],Newl),
         retract(option(Z,L)),assertz(option(Z,Newl)),!,
         deleteall([Q|_]).

deleteall(_).

list(A,L):-appnd([],A.L).

appnd(Lst,A.[A|Lst]).

/* are atoms equal*/
eq(X,X).

/*comparison of complex parameters is V=value or in the range V1....V2*/
compare(_,x,y).
compare([V|[]],V,y).
compare( [V1,V2],V,y):-(V1>=V,V>=V2);(V1=<V,V=<V2).
compare(_,_,n).

/* member  (X,list)   */
/* is X a member of the given list or set*/
member(X,[X|_]).
member(X,[_|Y]):-member(X,Y).

/* subset(list1,list2)*/
/* is list 1 a subset of list 2  */

subset([A|X],Y):-member(A,Y),subset(X,Y).

subset( [],Y ).

subtract(L,[],L):-!.
subtract([H|T],L,U):-member(H,L),!,subtract(T,L,U).
subtract([H|T],L,[H|U]):-!,subtract(T,L,U).
subtract(_,_,[]).
```

```
help:-write('DERKNIT'),nl,write('-----'),nl,nl,nl,
      write('Program to find an object given a partial list of facts'),nl,
      write('enter   ?-match([list of facts]).'),nl,nl,
      write('Objects in database.....'),nl,
      output.

output:-type(X,Y),write(X),write('--'),write(Y),nl,fail.
```

APPENDIX E

DEFECT CAUSES PROGRAM

```
cause(barre):-nl,
   write('  cause)                                        action  '),nl,
   write('  *****)                                        ******  '),nl,nl,
   write('knitting m/c                                  check positive feed'),nl,
   write('knitting m/c                                  no positive feed'),
   write('-check for improper cam adjustment'),nl,
   write('knitting m/c                                  check yarn tensions'),nl,
   write('knitting m/c                                  check cleanliness of m/c'),nl,
   write('knitting m/c                                  check m/c for dial:cylinder relationship'),nl,
   write('knitting m/c                                  check m/c for defective take-down mechanism'),nl,
   write('yarn                                          measure singles/folding/snarling twist'),nl,
   write('yarn                                          check yarn count').

cause(thicknthin):-nl,
   write('  cause                                         action  '),nl,
   write('  *****                                         ******  '),nl,nl,
   write('yarn                                          check for count variation within yarn package'),nl,
   write('yarn                                          check for twist variation within yarn package').

cause(slub):-nl,
   write('  cause                                         action  '),nl,
   write('  *****                                         ******   ),nl,nl,
   write('yarn                                          check evenness of yarn'),nl,
   write('yarn                                          refer to spinner - clearing/winding faulty').
```

```
cause(needleline):-nl,
   write('  cause                    action  '),nl,
   write('  *****                    ******  '),nl,nl,
   write('knitting m/c             check m/c for defective needle'),nl,
   write('knitting m/c             check m/c for damaged sinker'),nl,
   write('knitting m/c             check m/c for worn or unevenly spaced'),
   write('trick walls'),nl,
   write('knitting m/c             check m/c for dirty tricks'),nl,
   write('knitting m/c             check lubrication of knitting elements').

cause('dropstitch run'):-nl,
   write('  cause                    action  '),nl,
   write('  *****                    ******  '),nl,nl,
   write('knitting m/c             check m/c for broken needle or jack'),nl,
   write('knitting m/c             check needle for bent or stiff latch').

cause('tuck needle'):-nl,
   write('  cause                    action  '),nl,
   write('  *****                    ******  '),nl,nl,
   write('knitting m/c             check m/c for malfunctioning needle or jack'),nl,
   write('knitting m/c             check if take-down mechanism too loose'),nl,
   write('knitting m/c             check for improper stitch cam setting'),nl,
   write('knitting m/c             check if needles move too freely in tricks'),nl,
   write('knitting m/c             check if dial height set too low'),nl,
   write('knitting m/c             check for dirt in trick walls').

cause('rip needle'):-nl,
   write('  cause                    action  '),nl,
   write('  *****                    ******  '),nl,nl,
   write('knitting m/c             check m/c for damaged needle').
```

```
cause(dropstitches):-nl,
   write('  cause                                       action  '),nl,
   write('  ******                                      ******  '),nl,nl,
   write('knitting m/c                               check m/c for improperly set yarn carriers'),nl,
   write('knitting m/c                               check if yarn in wrong hole of carrier'),nl,
   write('knitting m/c                               check m/c for needle damage'),nl,
   write('knitting m/c                               check if take-down mechanism too loose'),nl,
   write('knitting m/c                               check fabric quality - if too tight/slack'),
   write('  adjust stitch settings accordingly'),nl,
   write('knitting m/c                               check if dial height too high'),nl,
   write('knitting m/c                               check m/c for positive feed slippage'),nl,
   write('knitting m/c                               check if needle timing set wrong'),nl,
   write('knitting m/c                               check if needle tricks clogged'),nl,
   write('knitting m/c                               check if dial latch closing under yarn carrier'),nl,
   write('knitting m/c                               check if dial latch closing near heel of carrier').

cause('slub hole'):-nl,
   write('  cause                                       action  '),nl,
   write('  *****                                       ******  '),nl,nl,
   write('yarn                                       refer to spinner - clearing/winding faulty').

cause('press off'):-nl,
   write('  cause                                       action  '),nl,
   write('  *****                                       ******  '),nl,nl,
   write('knitting m/c                               check fabric quality - if too tight/slack'),
   write(' adjust stitch cams accordingly'),nl,
   write('knitting m/c                               check if take-down mechanism is too tight'),nl,
   write('knitting m/c                               check positive feed system'),nl,
   write('knitting m/c                               check for dirty/clogged surfaces'),
   write('in/over which yarn passes'),nl,
   write('knitting m/c                               check for defective needles cutting the yarn'),nl,
   write('yarn                                       check for badly wound package'),nl,
   write('yarn                                       check strength of yarn'),nl,
   write('yarn                                       check for improper threading up of m/c').
```

```
cause('press off 1 bed'):-nl,cause('press off').

cause('knot hole'):-nl,
   write('  cause                              action  '),nl,
   write('  *****                              ******  '),nl,nl,
   write('yarn                               refer to spinner - clearing/winding faulty'),nl,
   write('knitter                            refer to knitter - badly tied knots').

cause(knots):-nl,
   write('  cause                              action  '),nl,
   write('  *****                              ******  '),nl,nl,
   write('yarn                               refer to spinner - clearing/winding faulty'),nl,
   write('knitter                            refer to knitter - badly tied knots').

cause('fly contamination'):-nl,
   write('  cause                              action  '),nl,
   write('  *****                              ******  '),nl,nl,
   write('yarn                               refer to spinner - ginning process faulty'),nl,
   write('knitter                            refer to knitter - cross-contamination of'),
   write('fibre during blowing down of m/c').

cause(neps):-nl,
   write('  cause                              action  '),nl,
   write('  *****                              ******  '),nl,nl,
   write('yarn                               refer to spinner - ginning process faulty').
```

APPENDIX F

KNOWLEDGE-BASE DRIVEN IMAGE CLASSIFICATION APPROACH.

PROGRAM TO GENERATE DATABASE

```
/*TEXPERT.PRO*/
/*Program to develop and test a database of the form entry
  (object,[list of features] )and causes.*/

exit:-retract(level(_)),assertz(level(main)).
begin:-exit,showmenu.
menu:-showmenu.
level(main).
context(none).
helpis(off).

help:-write('enter the first command from the menu '),nl,
      write('eg   enter test for text -database option'),nl,
      retract(helpis(_)),assertz(helpis(on)),level(X),menu(X).
nohelp:-retract(helpis(_)),assertz(helpis(off)).

showmenu:-level(X),menu(X).

menu(_):-helpis(off),nl,write('command ? ').
menu(main):-nl,nl,write('select option'),nl,
           write('         retrieve -database'),nl,
           write('         update -database'),nl,
           write('         show -database'),nl,
           write('         text -database'),nl,
           write('         save -database'),nl,
           write('         help  '),nl,
           write('         nohelp  '),nl.

/*principal functions*/

retrieve:-nl,nl,write('enter filename-or quit '),read(F),
         (F=quit;reconsult(F)),showmenu.

save:-nl,nl,write('enter filename-or quit  '),read(F),
      (F=quit;(tell(F),senfile,told)),showmenu.
senfile:-sendata,fail.
senfile.
sendata:-entry(Obj,Feat),write(entry(Obj,Feat)),write('.'),nl.
show:-output,showmenu.
output:-entry(O,F),write(O),write(F),nl,fail.
output.

update:-nl,nl,retract(level(_)),assertz(level(update)),showmenu.
```

```
menu(update):-nl,nl,write('select option'),nl,
              write('        new -entry'),nl,
              write('        delete -entry'),nl,
              write('        modify -entry'),nl,
              write('        show -entries'),nl,
              write('        help'),nl,
              write('        nohelp'),nl,
              write('        exit              ?'),nl.

new:-nl,nl,write('enter object name-or quit  '),
     read(Name),(Name=quit;assertz(entry(Name,[ ] ))),showmenu.

delete:-nl,nl,write('enter object name-or quit'),
        read(Name),(Name=quit;retract(entry(Name,_))),showmenu.

modify:-nl,nl,retract(level(_)),assertz(level(modify)),showmenu.

menu(modify):-nl,nl,write('select option'),nl,
              write('        show -database'),nl,
              write('        add -feature'),nl,
              write('        remove -feature'),nl,
              write('        current -object parameters'),nl,
              write('        change -context'),nl,
              write('        currently = '),context(O),write(O),nl,
              write('        words -in vocabulary'),nl,
              write('        help'),nl,
              write('        nohelp'),nl,
              write('        exit              ?'),nl,

add:-context(Obj),entry(Obj,L),
     write('enter the name of the feature  '),read(Name),nl,
     words(X,F),member(Name,X),write('available parameters '),write(F),nl,
     assertz(feature(Name)),
     write('do you wish to enter any parameters(y,n)? '),read(A),nl,
     setparams(A),buildlst( [] ),featurelist(N),retractall(featurelist(_)),
     retract(entry(Obj,L)),assertz(entry(Obj,[N|L] )),showmenu.

add:-write('unknown feature...please check word list '),nl,
     retractall(feature(_)),retractall(featurelist(_)).

current:-context(X),entry(X,L),nl,write(X),nl,write(L),showmenu.

getparams(quit):-retract(feature(quit)).
getparams(_):-write('enter the parameter (or quit if no more) '),
              read(Val),nl,asserta(feature(Val)),
              getparams(Val).

buildlst(L):-retract(feature(X)),buildlst([X|L] ).
buildlst(L):-assertz(featurelist(L)).

remove:-context(Obj),entry(Obj,L),write('enter name of feature '),
        read(N),nl,delfeatures(L,[],N),retract(featurelist(F)),
        retract(entry(Obj,L)),assertz(entry(Obj,F)),showmenu.
```

```
delfeatures([],New,_):-assertz(featurelist(New)).
delfeatures([[O|_]|T],M,O):-delfeatures(T,M,O).
delfeatures([H|T],M,O):-delfeatures(T,[H|M],O).

change:-nl,write('enter object name-or quit '),read(Obj),
        (Obj = quit ; dochange(Obj)  ),showmenu.

dochange(Obj):-entry(Obj,_),retract(context(_)),assertz(context(Obj)).
dochange(_):-nl,write('object not in database '),nl.

words:-words(A,B),write('feature synonyms...'),write(A),nl,
      write('available parameters...'),nl,write(B),nl,fail.
words.

/*feature vocabulary*/

words( [circle,round,circular],[radius,full,empty] ).
words( [line,lines,strokes,stroke,band,bands,stripes],
      [length,units,width,units,angle,units,straight,curved,complete] ).
words( [ladder,ladders,run,runs,ridge,ridges],[length,units,width,units,
      angle,units,straight,curved,complete] ).
words( [area],[area,units] ).
words( [x,xdim,xdimension,horizontal],[units,complete] ).
words( [y,ydim,ydimension,vertical],[units,complete] ).
words( [rectangle,box,oblong],[minordim,units,majordim,units,angle,
      units] ).
words( [marks,dots,blobs,specs,catches],[colour,number] ).
words( [thickening,bar],[length,units,width,units,angle,units] ).

/*  TEXT SECTION   */

text:-retract( level(_) ),assertz( level(text) ),showmenu.

menu(text):-nl,nl,write('select option'),nl,
           write('          match'),nl
           write('          match( [list of features] )'),nl,
           write('          help'),nl,
           write('          nohelp'),nl,
           write('          exit            ?'),nl.

match:-match([])).

/*--MATCH2.PRO--*/

/*---main clause....match( list of features)*/

match(Featureset ):-find( Featureset ),prnt.
```

```
/* assemble secondary list of options */

find( Featureset ):-entry(Y,L),subset(Featureset,L),
                    subtract(L,Featureset,Tests),
                    assertz( option(Y,Tests) ),fail.

/*purge option list to reduce it to minimum number of alternative */

find(_):-quest,nl,write('alternatives are....').

/* output list of alternatives */

prnt:-found(X),nl,write(X),retract(found(X)),fail.

prnt:-option(X,_),nl,write(X),retract(option(X,_)),fail.

prnt.

/* reduction process */

quest:-option(X,[Q|T] ),option(Y,_),
       not(eq(X,Y)),zap(Q),quest.

quest:-option(X,_),assertz(found(X)),fail.

quest.

/* handle a question */

/* question common to all options..delete it*/

zap(Q):-not(notall(Q)),deleteall(Q).
notall(Q):-option(Z,L),not(member(Q,L)).

/* ask question and execute response */

zap(Q):-ask(Q,A),execute(A,Q).

/*output question and read response */
ask(Q,A):-write('is the following true...y/n/x '),nl,
          write(Q),write(' ? '),read(A).

/*execute YES response....delete options not containing questions*/

execute(y,Q):-option(X,L),not(member(Q,L)),retract(option(X,L)),!,
              execute(y,Q).

/* execute NO response...delete options containing questions */
execute(n,Q):-option(X,L),member(Q,L),retract(option(X,L)),!,
              execute(n,Q).

/*execute all responses....delete all occurrences of question*/

execute(_,Q):-deleteall(Q).

execute(_,_).
```

```
/* delete all occurrences of the question from the option lists*/

deleteall(Q):-option(X,L),member(Q,L),list(Q.Lq),
              subtract(L,Lq,Newl),retract(option(Z,L)),
              assertz(option(Z,Newl)),!,deleteall(Q).

deleteall(_).

/*convert an atom to a list*/

list(A,L):-appnd([],A.L).
           appnd(Lst,A![A|Lst]).

/*are atoms equal?*/

eq(X,X).

/*---------member(X,list)----------------------*/

/* is X a member of the given list or set */

member(X,[X!_] ).
member(X,[_!Y] ):-member(X,Y).

/*-------subtract(list1,list2,list3)------------*/

subtract(L,[],L):-!.
subtract([H!T],L,U):-member(H,L),!,subtract(T,L,U).
subtract([H!T],L,[H!U] ):-!,subtract(T,L,U).
subtract(_,_,[] ).

/*---------------subset(list1,list2)------------*/

/*is list 1 a subset of list2*/

subset([A!X],Y):-member(A,Y),subset(X,Y).
subset([],Y).
```

APPENDIX F

DATABASE

```
entry(barre,[ [line,length,complete,width,1,horizontal,straight,
periodic] ] ).

entry(dropstitches,[ [round,radius,1,full],[area] ] ).

entry(rip_needle,[ ] ).

entry(thick_n_thin,[ ] ).

entry(slub_hole,[ ] ).

entry(knot_hole,[ ] ).

entry(press_off_1_bed,[ ] ).

entry(knots,[ ] ).

entry(fly_contamination,[ ] ).

entry(slub,[ [stroke,straight],[thickening,length,1,3,width,1,2,
horizontal,bar] ] ).

entry(needleline,[ [ladder],[line,length,complete,width,[0|1],1,
vertical,straight] ] ).

entry(dropstitch_run,[ [ladder],[line,length,2,4,width,2,4,vertical,
straight] ] ).

entry('tuck needle',[ [line,length,intermittent,width,[0|1],1,
vertical,straight,gathers] ] ).

entry(press_off,[ [circular,full,regular,hole,radius,2,5] ] ).

entry(neps[ ] ).
```

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